HIGHWAY RESEARCH REPORT

DYNAMIC TESTS OF A PRESTRESSED CONCRETE MEDIAN BARRIER TYPE 50

SERIES XXVI

FINAL REPORT

73-06

STATE OF CALIFORNIA

BUSINESS AND TRANSPORTATION AGENCY

DEPARTMENT OF PUBLIC WORKS

DIVISION OF HIGHWAYS

MATERIALS AND RESEARCH DEPARTMENT

RESEARCH REPORT

CA-HY-MR-6588-1-73-06

Prepared in Cooperation with the U.S. Department of Transportation, Federal Highway Administration March, 1973

STATE OF CALIFORNIA—BUSINESS AND TRANSPORTATION AGENCY RONALD REAGAN, Governor

DEPARTMENT OF PUBLIC WORKS
DIVISION OF HIGHWAYS
MATERIALS AND RESEARCH DEPARTMENT
5900 FOLSOM BLVD., SACRAMENTO 95819

March 1973

Final Report
M&R No. 656588
Item D-4-98

Mr. L. R. Gillis
Assistant State Highway Engineer
Project Development

Dear Sir:

Submitted herewith is a research report titled:

DYNAMIC TESTS
OF A
PRESTRESSED CONCRETE MEDIAN BARRIER TYPE 50,
SERIES XXVI

Principal Investigators
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Under the Supervision of
E. F. Nordlin and W. R. Juergens

Very truly yours,

JOHN L. BEATON
Materials and Research Engineer

TECHNICAL REPORT STANDARD TITLE PAGE

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16. ABSTRACT

The results of five vehicle impact tests into a Prestressed Concrete Barrier Type 50 are reported. This median barrier is 32 inches high with a profile similar to that developed by the State of New Jersey. The test barrier was slipformed onto existing asphalt concrete pavement and contained four prestressing strands encased in plastic sheaths. Because the barrier possessed no footing, the four strands were post-tensioned to provide adequate structural continuity along the longitudinal axis.

The nominal vehicle weight and impact velocity for the five tests were 4900 pounds and 65 mph, respectively. The angles of impact were 9.5 and 25 degrees. The level of prestress in the concrete was also varied during the test series because static test data from concrete strain gages indicated a substantial loss of effective prestress force due to friction and/or bond with the pavement.

It is concluded that this prestressed barrier without a footing possesses redirective, structural, and low maintenance properties equivalent to the lightly reinforced barrier with a footing which is currently constructed in California. The report contains detailed plans and specifications for construction of the prestressed barrier.

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The following staff members of the Materials and Research Department were instrumental in the completion of the tests reported herein:

Lee Staus Orvis Box Vince Martin	Preparation and operation of the test vehicle and other test equipment.
Richard Johnson Delmar Gans Stanley Law William Ng	Instrumentation of test vehicles and dummies.
Robert Mortensen Lewis Green	Data and documentary photography.

Various staff members of the Concrete Section of the Materials and Research Department assisted in the evaluation of the quality of the concrete in the test barrier.

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I. INTRODUCTION

In 1967 the California Division of Highways performed a series of full-scale impact tests on a Concrete Barrier Type 50, a concrete median barrier similar to the design developed by the State of New Jersey[1]*. The results of those tests and subsequent studies of accident statistics from freeway installations have demonstrated the effectiveness of this barrier for relatively narrow medians. Over the past few years, the use of this barrier has increased dramatically in California and throughout the nation. California installed about 26 miles of this barrier in 1971 and another 107 miles in 1972 at an average cost of about ten dollars per foot. At the end of 1972 over 1,000 miles of this type of barrier had been installed nationwide[2]. The demand for this barrier, coupled with recent developments in concrete slipforming techniques, encouraged highway engineers to seek more economical means of constructing the barrier without altering its effectiveness. Reducing the cost only one dollar per foot over 100 miles of barrier would amount to a savings of over $500,000. This research project was initiated to dynamically proof test a Prestressed Concrete Barrier Type 50 which promises not only to be more economical but also to reduce construction time on the highway.

Figure 1 illustrates a typical section of Concrete Barrier Type 50 constructed in California. Cast-in-place construction of this lightly reinforced barrier requires a four step process -- excavating for the footing, setting the forms, placing the concrete, and removing the forms. Since this barrier is often placed on narrow medians of existing freeways, one or more traffic lanes must be closed during the lengthy construction period. Such lane closures are not only inconvenient to the traveling public but create a substantial hazard for both the workmen and the motorists. Some contractors have been able to reduce both cost and construction time by casting the footing first and then slipforming the remainder of the barrier over dowels protruding from the cast-in-place footing. Through this experience, they have demonstrated that the slipforming technique can produce a barrier of appropriate concrete quality and shape.

With this development of slipforming techniques, it became apparent that substantial savings in cost and construction time might be achieved if the barrier were slipformed into

*Numbers in brackets refer to a Reference List at the end of this report.

place without a footing. Since elimination of the footing would potentially reduce the structural integrity and/or stability of the barrier, provisions were required to improve the structural continuity of the barrier along its longitudinal axis.

Slipforming equipment developed by P.C.E. Median Barriers, Incorporated, of Palm Desert, California, is capable of placing prestressing strands in the barrier during the slipforming process as shown in Figure 2. This firm constructed a 150-foot test section of the Prestressed Concrete Barrier Type 50 on the asphalt concrete pavement at the California Division of Highways test facility. The prestress strands were greased and encased in plastic sheathing such that they could be post-tensioned after the concrete had gained adequate strength. This test section was subjected to five full-scale impact tests to determine whether or not its performance was equivalent to the previously tested lightly reinforced, cast-in-place, Concrete Barrier Type 50 with a footing.

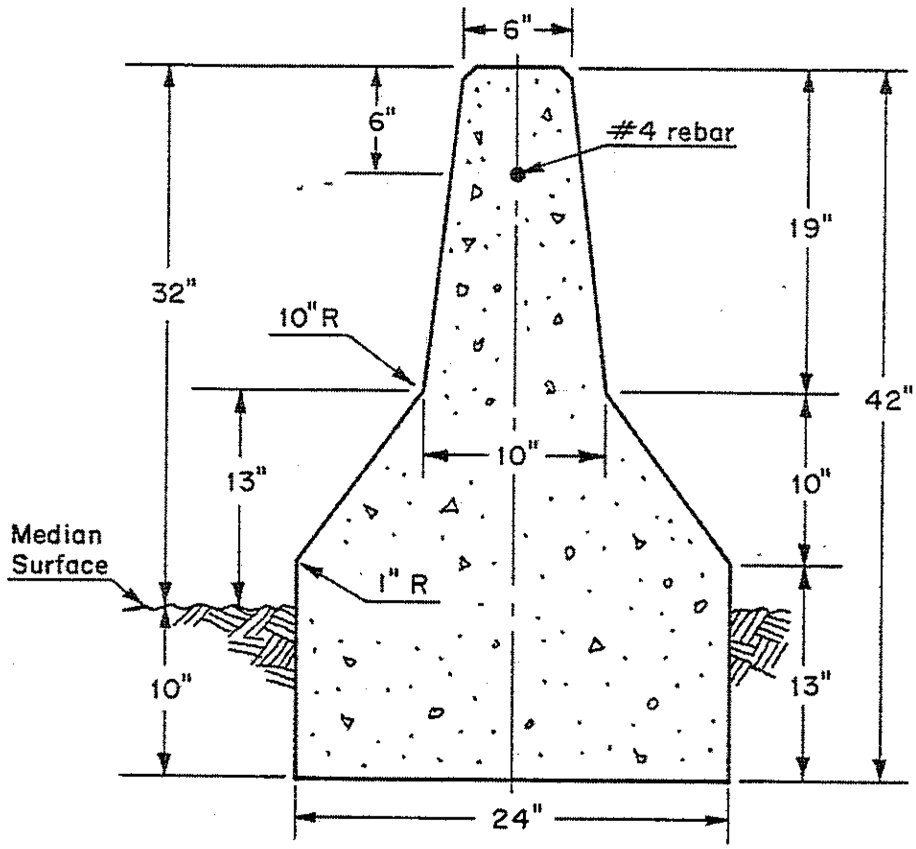


FIGURE 1, TYPICAL SECTION OF CONCRETE BARRIER TYPE 50

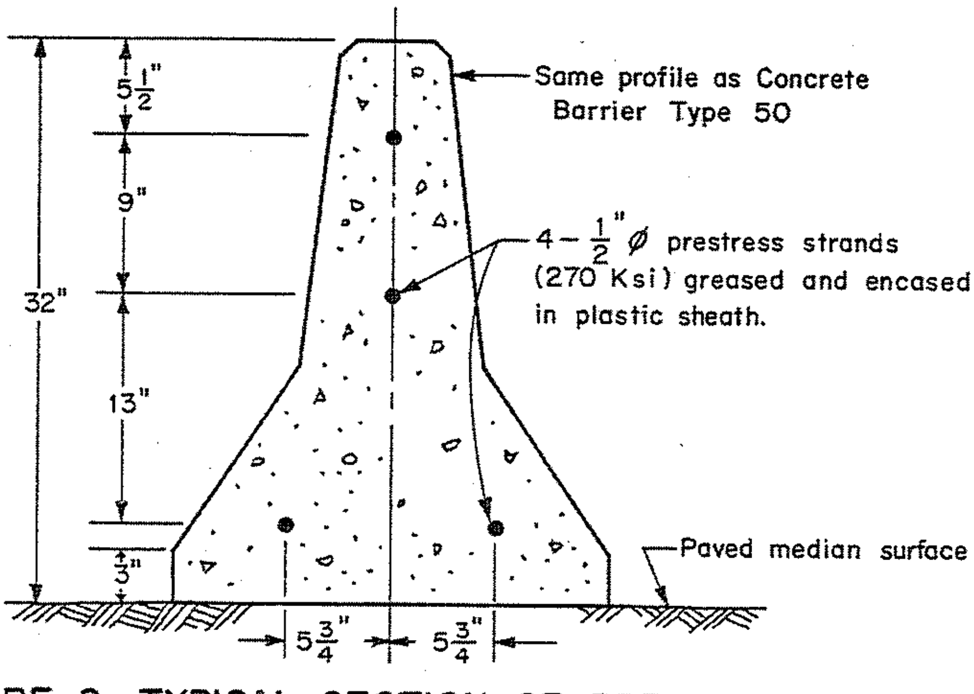


FIGURE 2, TYPICAL SECTION OF PRESTRESSED CONCRETE BARRIER TYPE 50

II. CONCLUSIONS AND IMPLEMENTATION

For impact conditions normally encountered on California freeways, the Prestressed Concrete Barrier Type 50 possesses redirective and low maintenance properties equivalent to the Concrete Barrier Type 50. For impact conditions exceeding the severity of a 4,900 pound sedan impacting at 65 mph and an angle of 25 degrees, the redirective properties of either of these Type 50 barriers are unknown, and could only be determined from further testing.

Presented in the Appendix are plans and specifications which were drafted in a cooperative effort between the Traffic, Bridge, and Materials and Research Departments of the California Division of Highways to allow construction of the Prestressed Concrete Barrier Type 50 as an acceptable alternate to the Concrete Barrier Type 50. Among their requirements, these plans and specifications: (1) provide for the placement of the Prestressed Concrete Barrier Type 50 on relatively flat, paved medians, (2) limit the maximum prestressing length to 450 feet, and (3) require a cast-in-place, reinforced joint between the prestressed sections.

These plans do not provide for the placement of this barrier on sawtooth medians, i.e., where the cross slopes of the two opposing roadways do not intersect in the median. The use of prestressing in barriers on sawtooth medians may require relocation and possible addition of prestressing strands based on the area and center of gravity of the concrete section. A difference in grade on the two sides of a barrier in a sawtooth median of more than six inches may warrant adjustments in the strand requirements. The barrier design tested is considered adequate for use where the difference in grade is six inches or less. Other configurations of the Prestressed Concrete Barrier Type 50, when required, would need to be designed with consideration given to strand location and number

Because the Prestressed Concrete Barrier Type 50 offers potential reduction of both cost and construction time, initial installations on California freeways are expected in the near future.

III. TECHNICAL DISCUSSION

A. Test Conditions

1. Barrier Design and Construction

The basic objective of this barrier design was to produce a barrier that is equivalent to the Concrete Barrier Type 50 illustrated in Figure 1 while substantially reducing both cost and construction time on the highway. In order to achieve this objective, the structural design criteria were as follows:

a. The shape of the barrier above the pavement surface must be identical to the Concrete Barrier Type 50.

b. The barrier must be able to withstand the impact of a 4,900 pound sedan hitting the barrier at 65 mph at an angle of 25 degrees without any significant movement or damage to the barrier.

c. Provisions must be made to resist cracking due to differential settlement and to reduce the possibility of chunks of concrete being thrown into opposing traffic upon impact.

The prestressed, slipform design shown in Figure 2 offered promise of meeting all these criteria. However, since the means by which the barrier absorbs the dynamic loads imposed upon impact are not fully understood, the proposed barrier design could not be judged analytically, and, therefore, was subjected to full-scale proof tests.

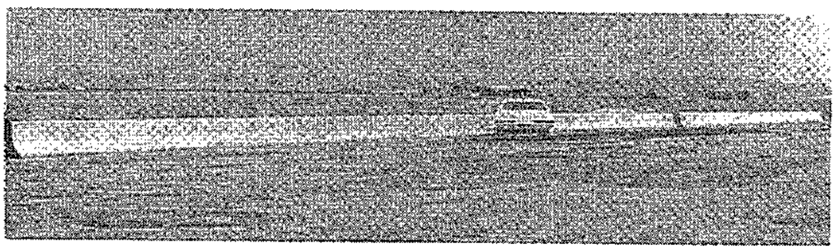


FIGURE 3, THE 150-FOOT TEST BARRIER IS ON NEAR SIDE OF JOINT. THE 150-FOOT SECTION ON FAR SIDE OF JOINT WAS NOT TESTED.

The test installation shown in Figure 3 was a 150-foot section of barrier slipformed onto the surface of the existing asphalt concrete pavement at Lincoln Municipal Airport. No attempt was made to thoroughly clean the pavement prior to placement of the concrete except for sweeping to remove loose gravel, dirt clods, etc. The four prestress strands were placed simultaneously with the concrete by feeding the strands through the slipform. The strands were 1/2 inch diameter, 270 ksi steel, conforming to ASTM Designation A416, encased in plastic sheathing which was packed with grease. The concrete mix was designed to possess a minimum 28 day strength of 3500 psi. At each end of the 150-foot section was a 1/4 inch thick steel plate which served as both end forms and a flat surface for the prestress bearing plates as shown in Figure 4. The bearing plates were 3 3/4 inch square steel plates with conical holes to receive the prestress wedges.

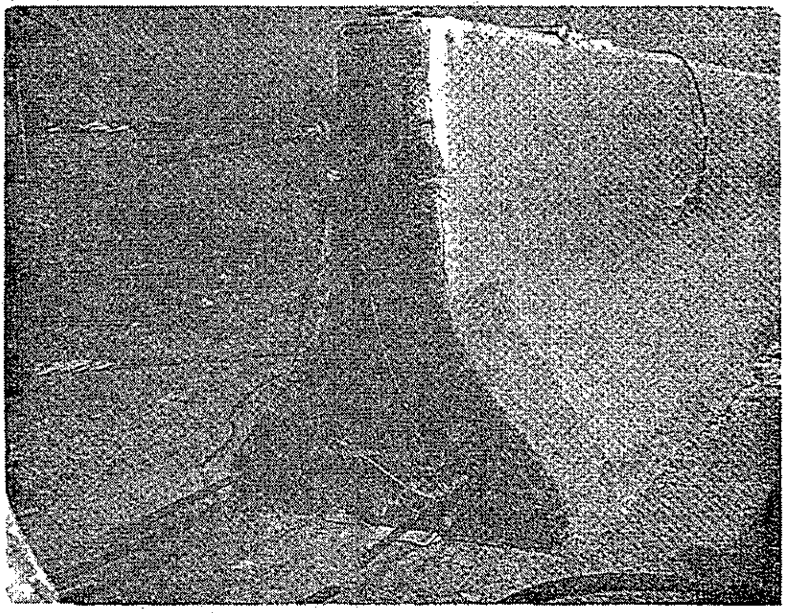


FIGURE 4, GAP BETWEEN BARRIER SECTIONS PRIOR TO PLACEMENT OF STEEL COVER PLATES. STRAND ANCHORAGE HARDWARE AND LOAD CELLS ARE IN PLACE.

Proper placement of this barrier requires careful control of the concrete mix and, of course, proper control of the slipform equipment. For the slipforming process, the fresh concrete must possess very little slump while retaining workability. Improper control of the concrete mix can result in excessive slump or cracking as illustrated in Figure 5. After experimenting with several mix designs, the developer of the slipform equipment chose the following mix for the test barrier: a 3/4 inch maximum aggregate from California's Bear River; a water/cement ratio of 0.49; six sacks of Type II cement; and 17 ounces of water reducing admixture per cubic yard. The admixture successfully enhanced workability while maintaining a one inch slump during construction of the test barrier.

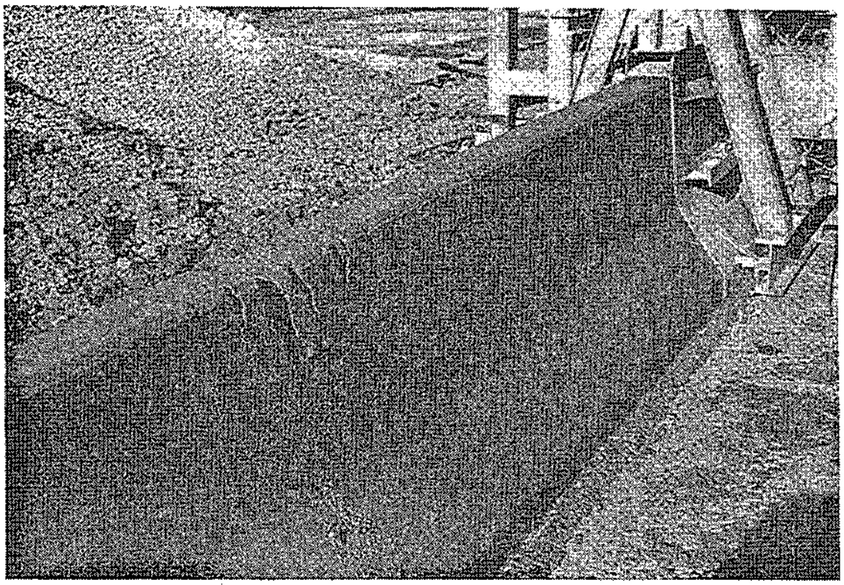


FIGURE 5, CRACKS RESULTING FROM
IMPROPER CONTROL OF CONCRETE MIX.

Having learned that conventional transit mix trucks could not discharge the stiff mix rapidly enough for the slipforming operation, the developer used special transit mix trucks with modified fins to increase the discharge rate. Fed by these trucks, the slipform equipment placed the test barrier at a rate of about four feet per minute with very little hand finishing required. Extensive hand finishing was required on the first two feet of barrier as the machine moved away from the end form, but the remainder of the 150-foot section was virtually free of hand finishing. The alignment of the barrier was true and the finish was smooth and free of rock pockets and air bubbles except for small rock pockets near the base at the starting point. A white pigmented curing compound was sprayed on the surface and was not removed. A few vertical shrinkage cracks which traversed the entire perimeter of the barrier's cross-section appeared during the cure period, but tended to close up during the prestressing operations. The compressive strength of the concrete was 3,260 psi when prestressed at the age of 5 days, and 5,376 psi when subjected to the first two tests at the age of 31 days.

Following construction of the test barrier, a second barrier was installed in line with the test barrier leaving a three foot gap between the two barriers. This second barrier was identical to the test barrier except that it was placed on top of a cast-in-place footing. It was to be proof-tested in the case of failure of the test barrier, and, consequently, was never subjected to any impact tests. However, the three foot gap did provide for a prototype of the construction joint proposed by the developer. As shown in Figure 6, the gap was spanned by two steel plates which were bent to match the contour of the barrier. After the strands were prestressed, the steel plates were bolted in place but they did not provide any structural continuity through the joint.

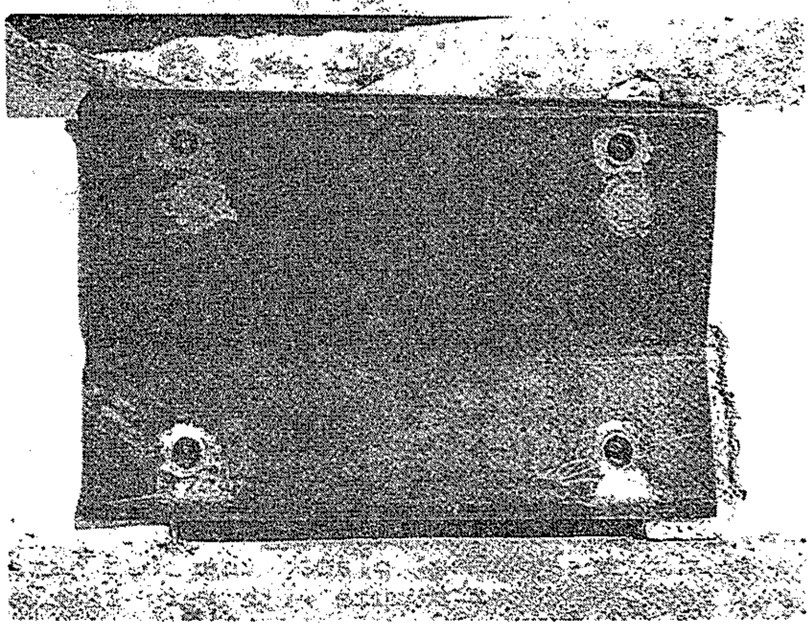


FIGURE 6, STEEL COVER PLATES PROVIDE GEOMETRIC CONTINUITY THROUGH GAP BETWEEN BARRIER SECTIONS.

Figure 7 illustrates the size and complexity of the slipform equipment used to construct the test barrier. The barrier was placed on a very flat portion of the Lincoln Airport runway because the equipment did not possess automatic means of controlling line and grade. The operator controlled line and grade by manually adjusting the machine to follow a string line. This method proved successful for placement of the test barrier, but more positive means must be developed for less ideal surfaces to be encountered in practice. Proper placement of the barrier required the careful scheduling of the transit mix trucks. If the slipforming process is not performed continuously, substantial manual finishing may be required at locations along the barrier where the equipment pauses.

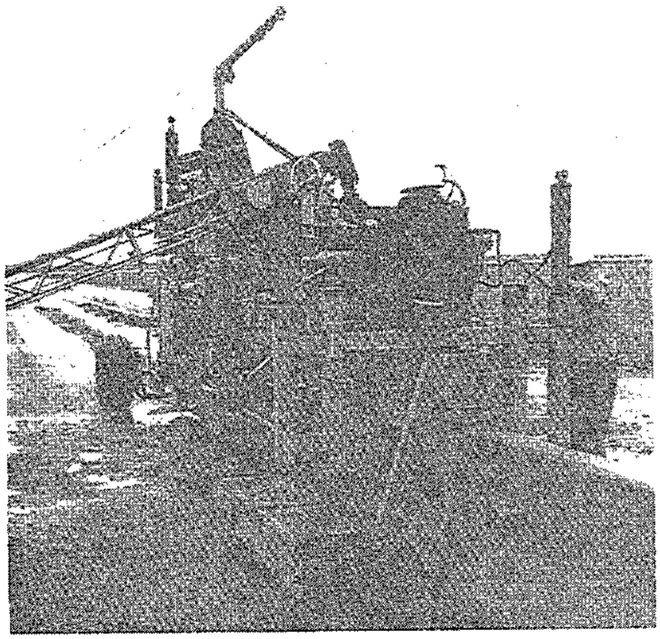


FIGURE 7, SLIPFORMING THE TEST BARRIER ONTO THE ASPHALT CONCRETE PAVEMENT. CONCRETE IS DISCHARGED FROM TRANSIT MIX TRUCKS ONTO THE CONVEYOR SHOWN AT LEFT.

2. Prestress Losses

During prestressing operations, stresses in both the concrete and the strands were monitored by surface strain gages and load cells. The data obtained from load cells located at each end of individual strands indicated no significant loss of prestress in the strands due to friction acting upon the strands. After jacking the 150-foot strands individually to 31 kips, the loss due to seating the wedges was about 3 kips per strand. The loss due to creep of the steel and concrete reduced the load to a stable value of about 25 kips per strand after about 7 days.

Although the tension in the strands was uniform throughout the length of the barrier, the prestress in the concrete varied significantly. The data obtained from a total of eight strain gages located on the surface of the concrete at the end and center of the 150-foot test barrier indicate that the effective prestress in the concrete is reduced as shown in Figure 8. This reduction in prestress in the concrete is due to friction and/or bond between the barrier and the pavement, and is, therefore, dependent upon many variables including type, condition, and thickness of pavement and length of barrier. The stresses shown in Figure 8 should, therefore, be considered only an estimate of stresses existing in actual installations. More exacting data could only be obtained by extensive testing. The description of instrumentation and details of obtaining this data are presented in the Appendix.

Based on Figure 8, the prestress conditions in the barrier for Test 265 were chosen to simulate the stress at the center of a 450-foot installation of prestressed barrier. Although the concrete stresses in any particular barrier are dependent upon the particular pavement conditions, the stresses existing at the center of the test barrier for Test 265 are considered reasonably conservative for a 450-foot barrier since they were relatively low -- about 130 psi at the top and 72 psi at the bottom of the barrier.

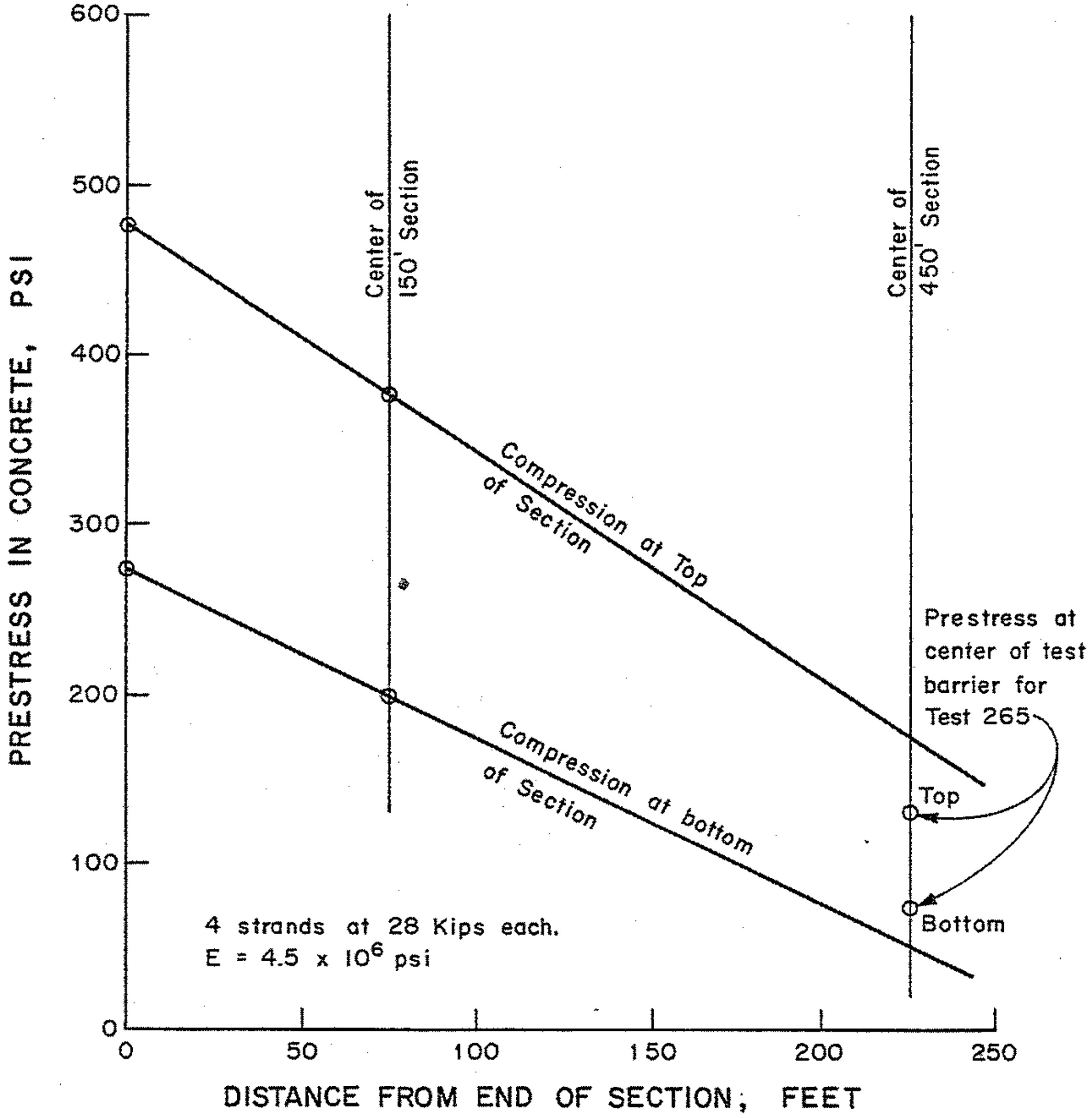


FIGURE 8, ESTIMATED LOSS OF PRESTRESS
IN CONCRETE DUE TO FRICTION/BOND WITH PAVEMENT

3. Test Parameters

The following test parameters were varied during the course of the five tests: angle of impact, point of impact on the barrier, prestress in the concrete at the point of impact, and model of vehicle. These variables are summarized in the following table:

Test Number	Angle of Impact	Approximate Point of Impact	Approx. Concrete Prestress, psi Top	Approx. Concrete Prestress, psi Bottom	Model of Vehicle
261	9.5°	End	463	269	1970 Mercury
262	25.0°	Center	374	198	1970 Mercury
263	25.0°	End	446	251	1970 Mercury
264	25.0°	Center	281	148	1968 Dodge
265	24.0°	Center	130	72	1969 Dodge

Other parameters which were held nominally constant throughout the test series were the vehicle weight of 4,900 pounds and planned velocity of 65 mph.

The Highway Research Board Committee on Guardrails and Guideposts [3] recommends that proof tests of guardrail systems be made with a 4,000 pound car traveling at 60 mph and impacting the barrier at angles of 7 and 25 degrees. It also recommends that proof testing include impacts near the end of the barrier. This series of tests met or exceeded all these recommendations. The vehicle weight of 4,900 pounds and speed of 65 mph exceed the HRB recommendations because it is felt that this weight and speed is more representative of vehicles on California highways. The angle of impact in Test 261 was intended to be 7 degrees but substandard performance of the guidance equipment resulted in a 9.5 degree impact angle.

Statistical data indicates that more than half of the vehicles which run off the roadway do so at an angle of 9.5 degrees or less[4]. Based on this data, a majority of the impacts into this barrier would be less severe than Test 261. The same study indicates that about 90 percent of the vehicles leaving the roadway do so at an angle of 25 degrees or less. Since these statistics included vehicles of all sizes and speeds, one can see that the probability of accidents occurring which are as severe as Tests 262 through 265 is quite small.

The points of impact and levels of prestress in the concrete were selected to proof test the structural integrity of the barrier under various simulated field conditions. In the final test the prestress in the concrete simulated the prestress conditions anticipated to occur at the center of a 450-foot section of barrier. It was assumed that the maximum practical prestressing length would be 450 feet.

The original test plan did not include the model of vehicle as a variable. However, having observed that post impact behavior of the Mercury sedans in Tests 262 and 263 differed significantly from that of the Dodge sedan in Test 162[1], Dodge sedans were used in subsequent tests to determine whether this post impact behavior was a characteristic of the barrier or of the particular vehicle.

4. Test Equipment and Procedure

The test vehicles used in this study were 1970 Mercury, 1968 Dodge, and 1969 Dodge sedans. Their test weights, including on-board instrumentation and dummy, were 4,960, 4,780, and 4,860 pounds respectively. These vehicles were retired California Highway Patrol sedans modified for test purposes. Control of the vehicle during the impact approach was accomplished by remote radio control from a command car following approximately 100-feet behind the test vehicle.

High speed and normal speed movie cameras and still cameras were used to record the impact event and the vehicle and barrier condition before and after impact.

To obtain data on the motions and deceleration forces a human would be subjected to during these impacts, an anthropometric dummy was placed in the driver's seat of the crash vehicle for all of the tests reported herein. The dummy, Sierra Stan (Model P/N 292-850), manufactured by Sierra Engineering Company, is a 50th percentile male weighing 165 lbs. It was restrained during the tests by a standard lap belt.

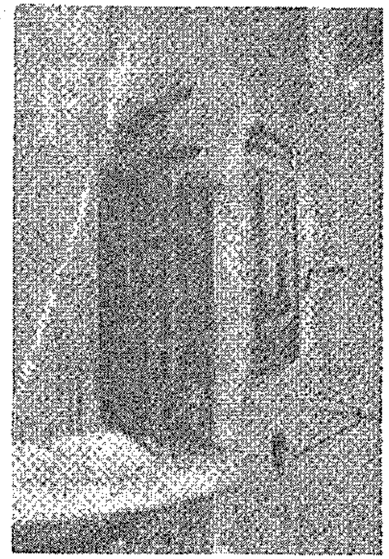
Accelerometers were mounted on the vehicle and dummy to obtain deceleration data for use in judging the severity of injuries to passengers. A mechanical Impactograph mounted on the floorboard behind the front seat served as a backup for the accelerometers.

The Appendix contains a detailed description of: the test vehicle mechanical instrumentation; photographic equipment and data collection techniques; electronic instrumentation and data reduction methods; accelerometer and impactograph records.

B. Test Results

1. Introduction

Figures 9 through 13 summarize the results of the five tests. The approximate path of the vehicle following impact is estimated from photographic data and marks on the barrier and pavement. The exit angle represents the direction the center of gravity of the vehicle is moving immediately following final contact with the barrier and is estimated from cameras mounted over the impact area. The values of maximum vehicle rise shown in these figures represent the maximum rise of the target on the left front fender (impact side) as the vehicle is redirected. The following descriptions of the individual tests are intended to supplement the figures.



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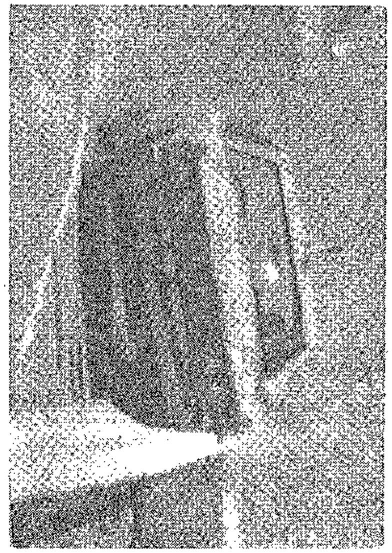

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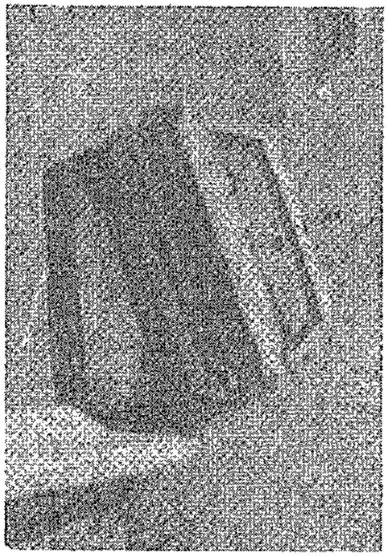

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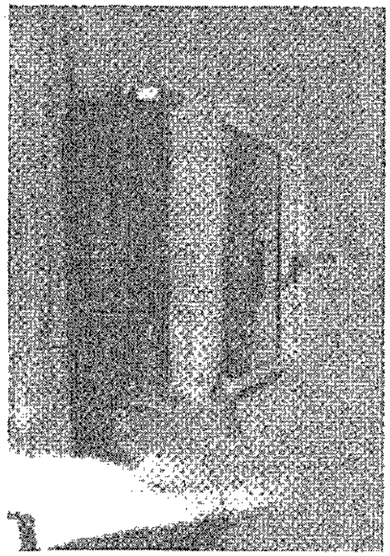

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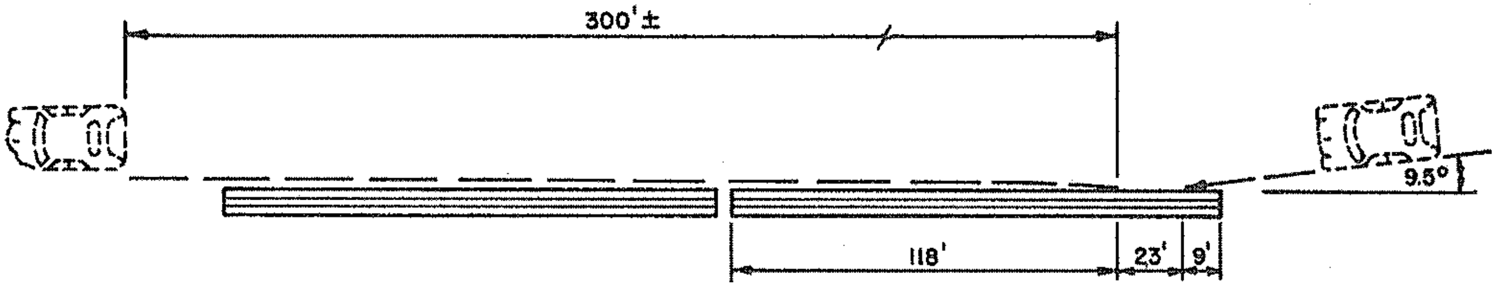
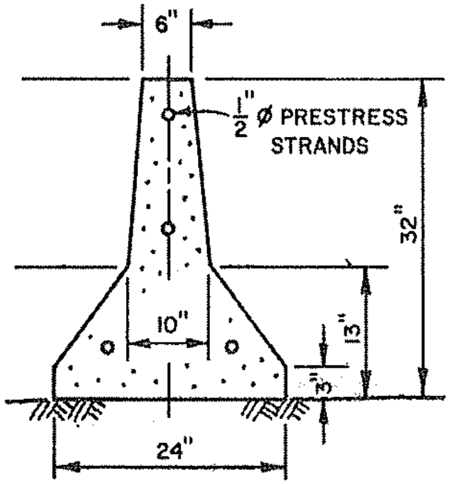
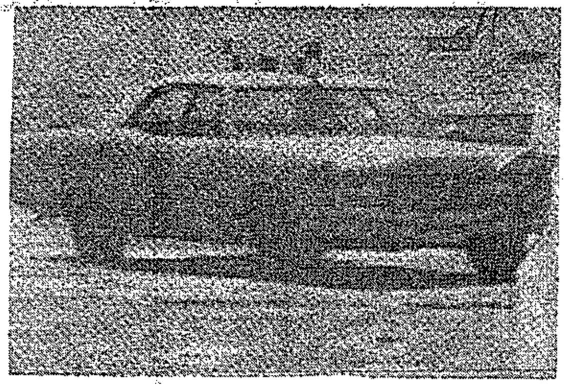




BARRIER TESTED	PRESTRESSED TYPE 50	TEST NO.	261
STRANDS (as seated)	4 @ 28 K ea.	DATE	4/21/72
LENGTH OF SECTION	150'	VEHICLE	1970 Mercury
PASSENGER COMP. DECEL. . . Long.	0.6 g	IMPACT VELOCITY	61 mph
(Highest 50 ms average). . . . Lat.	3.9 g	APPROACH ANGLE	9.5°
MAX. VEHICLE RISE	1.9'	VEHICLE WEIGHT	4960 lb
VEHICLE EXIT ANGLE	0°	(W/Dummy & Instrumentation)	
VEHICLE DAMAGE	Minor	DUMMY RESTRAINT	lap belt
BARRIER DAMAGE	None		

FIGURE 9, TEST 261



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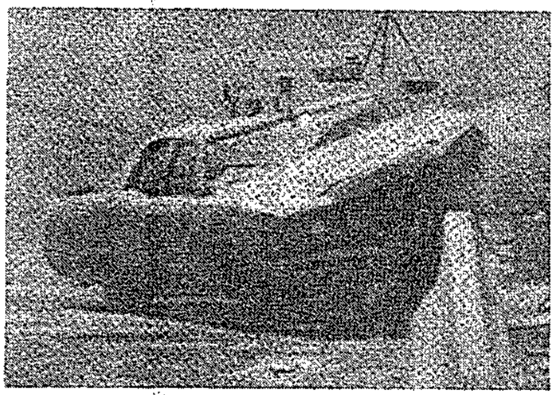

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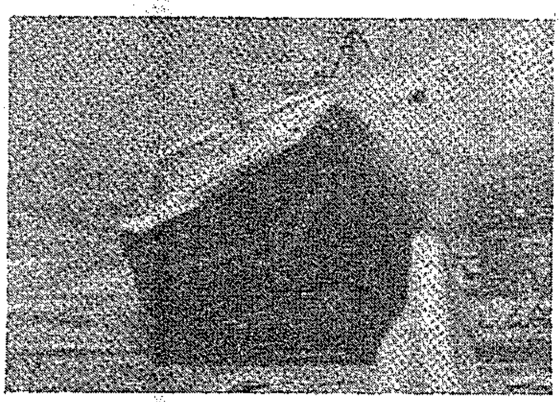

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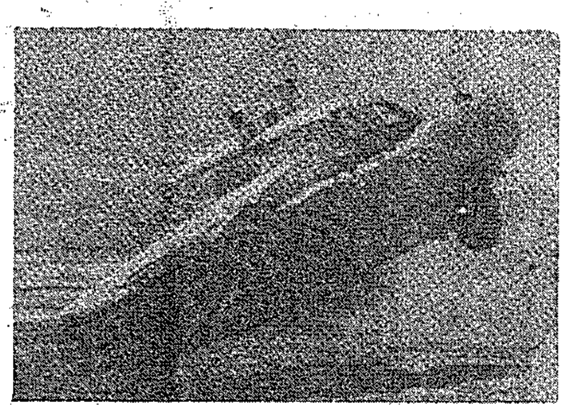

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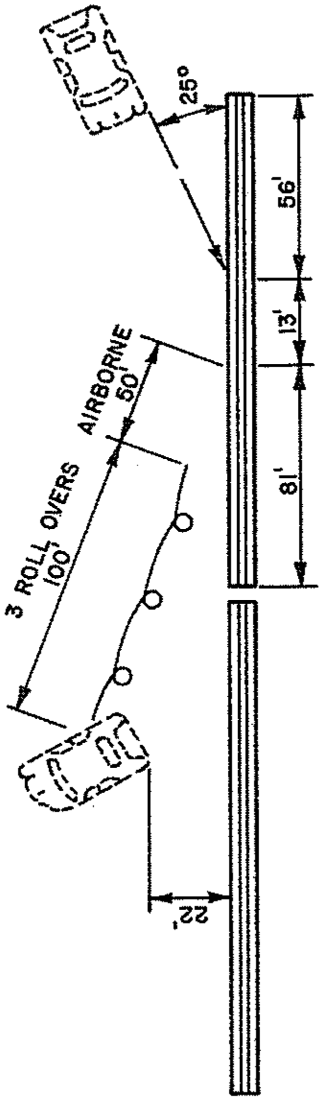


BARRIER TESTED	PRESTRESSED TYPE 50
STRANDS (as seated)	4 @ 28 K ea.
LENGTH OF SECTION	150'
PASSENGER COMP. DECEL. ..Long.	7.0 g
(Highest 50ms average) .....Lat.	11.6 g
MAX. VEHICLE RISE	2.8'
VEHICLE EXIT ANGLE	No Data
VEHICLE DAMAGE	Total
BARRIER DAMAGE	None

TEST NO.	262
DATE	4/21/72
VEHICLE	1970 Mercury
IMPACT VELOCITY	59 mph
APPROACH ANGLE	25°
VEHICLE WEIGHT (W/Dummy & Instrumentation)	4960 lb
DUMMY RESTRAINT	lap belt

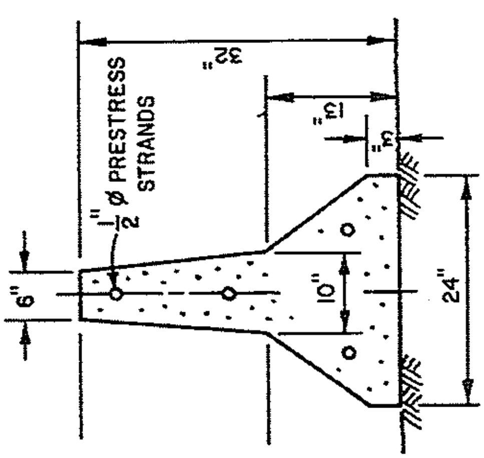
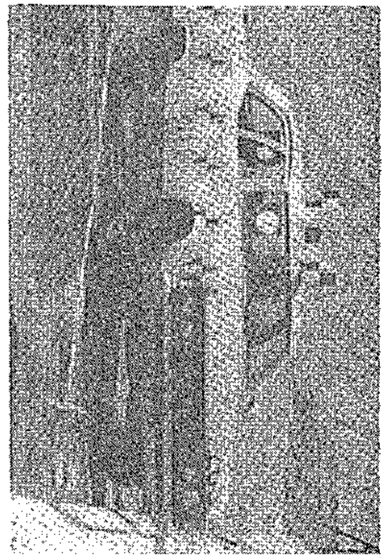


FIGURE 10, TEST 262



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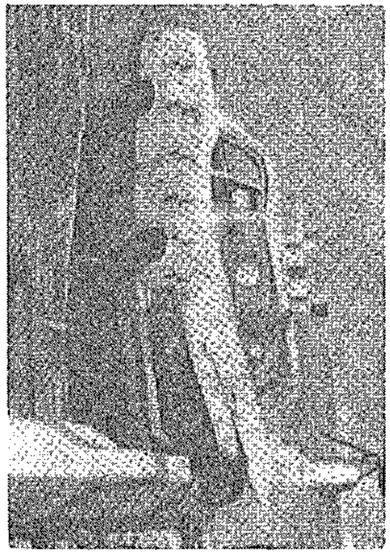

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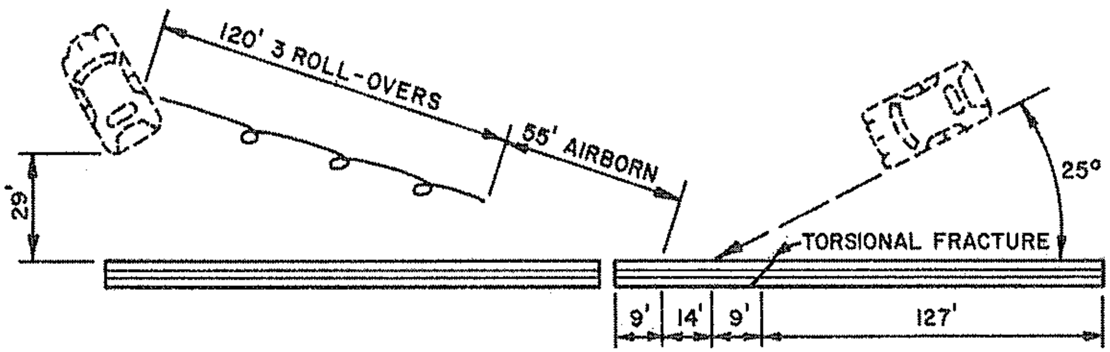
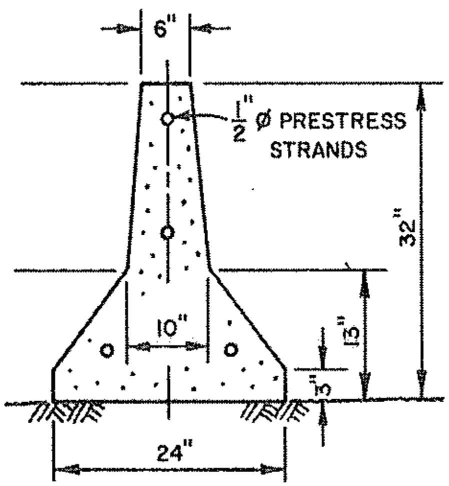
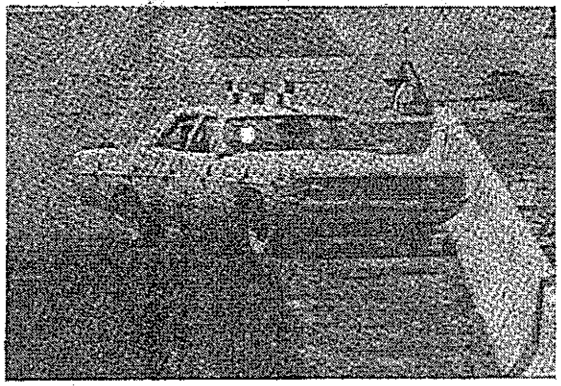




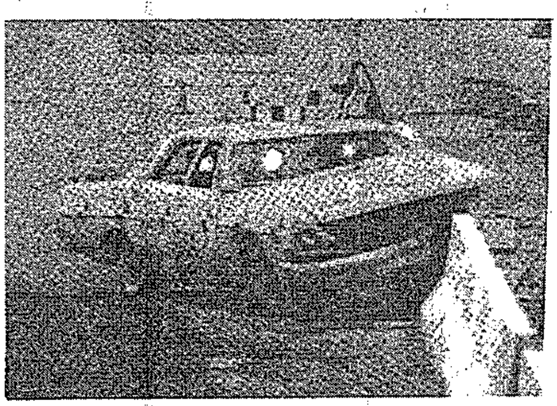
BARRIER TESTED	PRESTRESSED TYPE 50
STRANDS (as seated)	4 @ 28 K ea.
LENGTH OF SECTION	150'
PASSENGER COMP. DECEL...Long.	No Data
(Highest 50 ms average).....Lat.	No Data
MAX. VEHICLE RISE	2.7'
VEHICLE EXIT ANGLE	8°
VEHICLE DAMAGE	Total
BARRIER DAMAGE	Fractured

TEST NO.	263
DATE	5/4/72
VEHICLE	1970 Mercury
IMPACT VELOCITY	66 mph
APPROACH ANGLE	25°
VEHICLE WEIGHT (W/Dummy & Instrumentation)	4960 lb
DUMMY RESTRAINT	lap belt

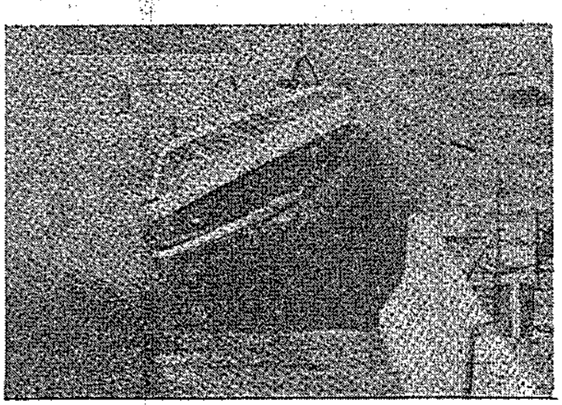
FIGURE 11, TEST 263



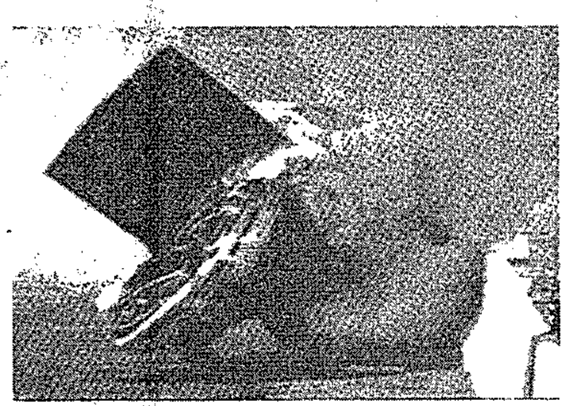
IMPACT



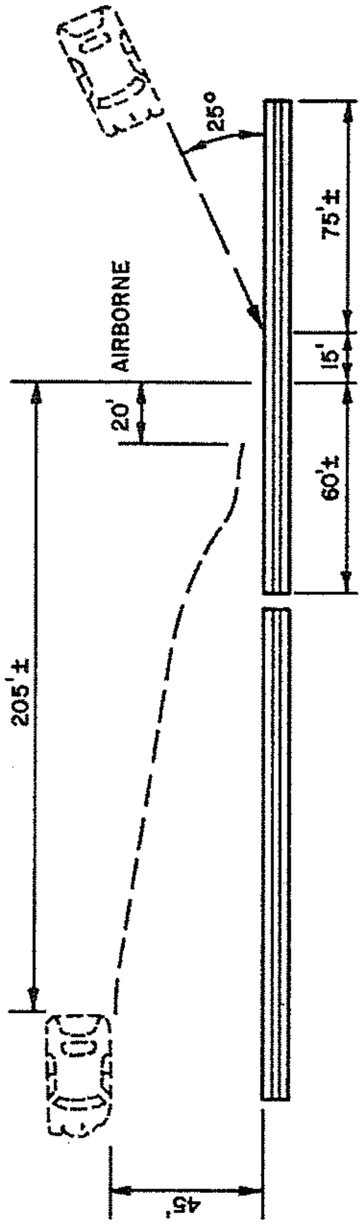
I+.100 SEC.



I+.250 SEC.



I+.600 SEC.



BARRIER TESTED	PRESTRESSED TYPE 50
STRANDS (as seated)	3 @ 28 K ea.
LENGTH OF SECTION	150'
PASSENGER COMP. DECEL. . . Long.	5.2 g
(Highest 50 ms average) . . . . . Lat.	13.0 g
MAX. VEHICLE RISE	3.0'
VEHICLE EXIT ANGLE	5°
VEHICLE DAMAGE	Severe Frontal
BARRIER DAMAGE	None

TEST NO.	264
DATE	6/2/72
VEHICLE	1969 Dodge
IMPACT VELOCITY	64 mph
APPROACH ANGLE	25°
VEHICLE WEIGHT	4860 lb
(W/Dummy & Instrumentation)	
DUMMY RESTRAINT	lap belt

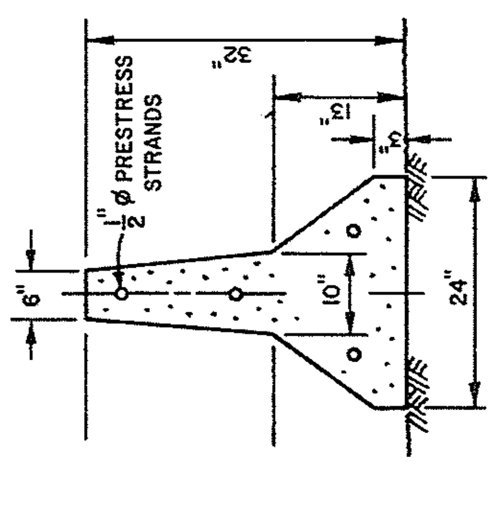
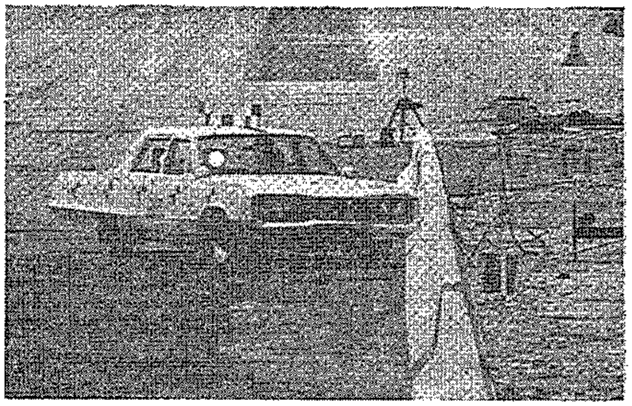
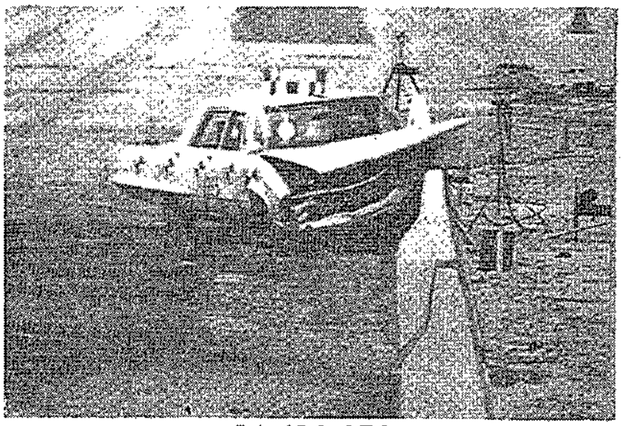


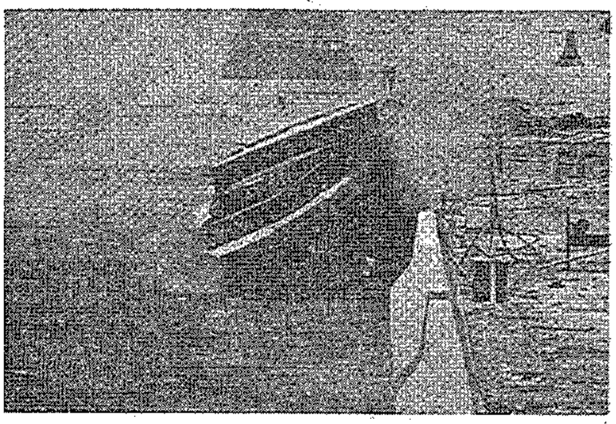
FIGURE 12, TEST 264



IMPACT

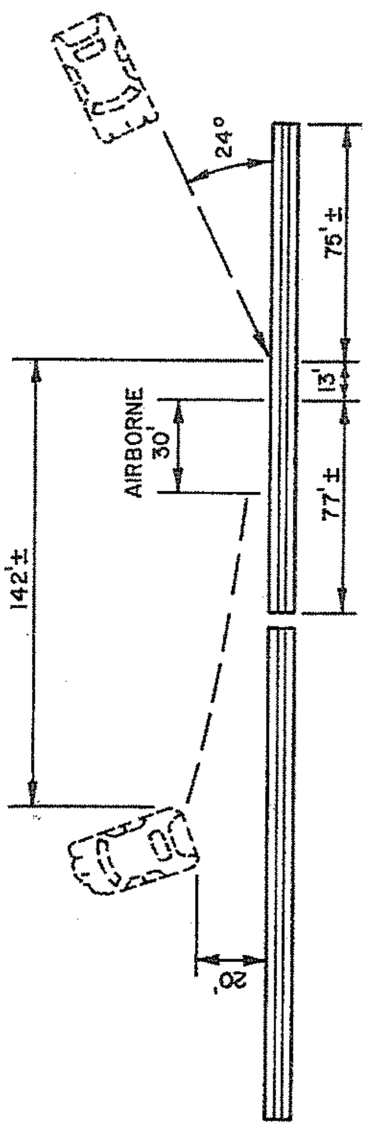


I+.100 SEC.



I+.250 SEC.

I+.550 SEC.



BARRIER TESTED	PRESTRESSED TYPE 50
STRANDS (as seated)	4 @ 10 K ea.
LENGTH OF SECTION	150'
PASSENGER COMP. DECEL. ..Long.	No Data
(Highest 50ms average)....Lat.	No Data
MAX. VEHICLE RISE	3.7'
VEHICLE EXIT ANGLE	4°
VEHICLE DAMAGE	Severe frontal
BARRIER DAMAGE	Hairline fracture

TEST NO.	265
DATE	6/16/72
VEHICLE	1968 Dodge
IMPACT VELOCITY	62 mph
APPROACH ANGLE	24°
VEHICLE WEIGHT (W/Dummy & Instrumentation)	4780 lb
DUMMY RESTRAINT	lap belt

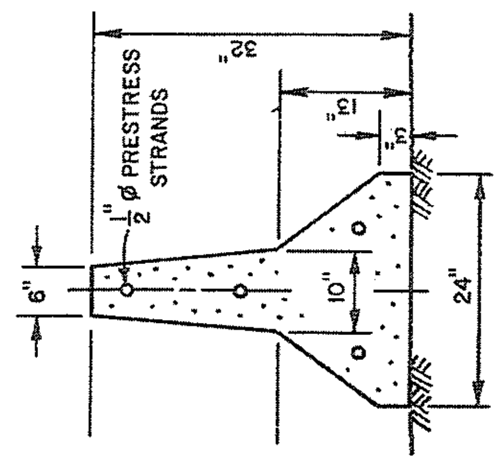


FIGURE 13, TEST 265

2. Test 261

Test 261 was conducted to determine the redirective qualities of the barrier when impacted at a low angle by a vehicle traveling at high speed. The angle of impact was intended to be 7 degrees as shown in Figure 14 but substandard performance of the guidance equipment resulted in a larger impact angle.

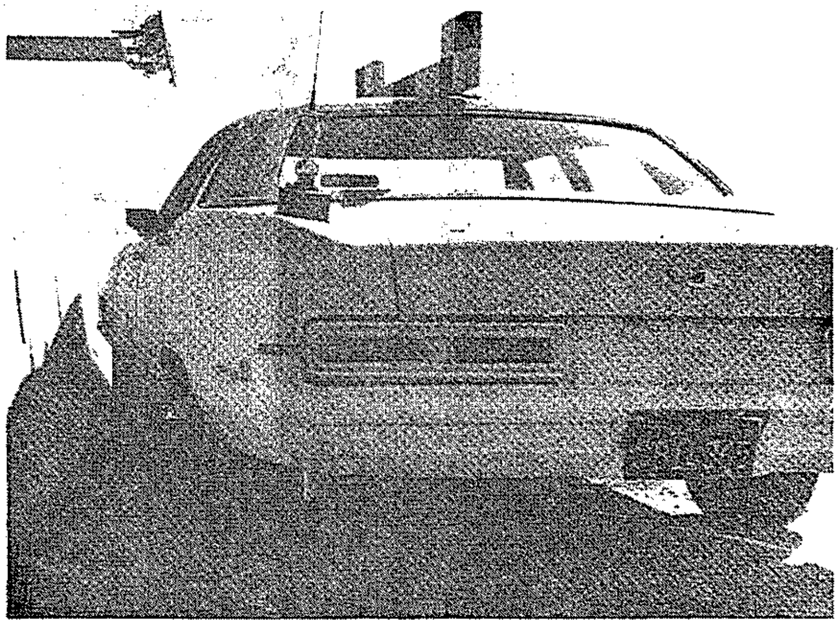


FIGURE 14, FOR A 7 DEGREE IMPACT ANGLE, THE TIRE CONTACTS THE BARRIER BEFORE THE BUMPER.

A 1970 Mercury sedan traveling at 61 mph hit the barrier at an angle of 9.5 degrees from the barrier. The left front tire contacted the barrier at the same time as the left front fender, rode up to a height of 1.4 feet in the first 10 feet of contact, and remained at that height until it left the barrier 23 feet from the point of contact. Upon leaving the barrier, the car remained parallel to the barrier and within three feet of it for 300± feet although no attempt was made to steer the car.

Vehicle damage was minor, consisting of slight deformation to the left fender and the left end of the front bumper and paint scratches along the length of the left side of the vehicle as shown in Figure 15. There was no mechanical damage to the vehicle and it was used for a subsequent test the same day without any repairs. There was no barrier damage except for slight scratches and, of course, tire and body marks as shown in Figure 16.

The 165 pound dummy, restrained in the driver's position by a lap belt, leaned against the left door upon impact and then leaned back to its right where it was restrained in a semi-upright position by the lap belt. Inspection of the dummy and the vehicle interior revealed no indications of contact between the dummy's head and the vehicle and no damage to the vehicle's interior. This knowledge, when combined with the acceleration data, indicates that a live driver would have suffered only minor injuries, if any at all.

FIGURE 15, MINOR DAMAGE RESULTING FROM
9.5 DEGREE, 65 MPH IMPACT, TEST 261.

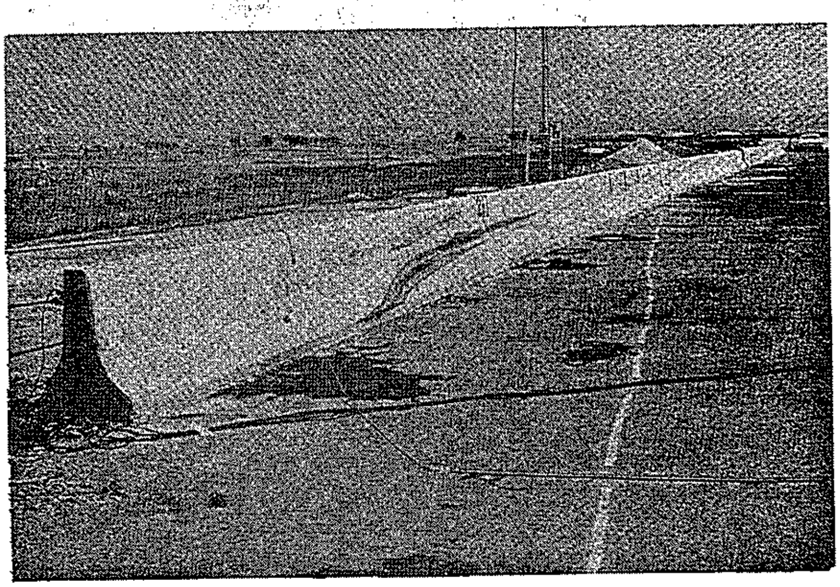


FIGURE 16, TIRE AND BODY MARKS FROM
9.5 DEGREE ANGLE IMPACT, TEST 261.
NOTE FINAL LOCATION OF CAR.

3. Test 262

Test 262 was conducted to test the ability of the barrier to retain and redirect a vehicle under very severe impact conditions as shown in Figure 17. Since these test conditions represent the most severe test of the barrier's structural integrity, the barrier was hit at one of its potentially weakest points -- at the center of the 150-foot section. The effective prestress in the concrete at this point was estimated to be 374 psi at the top of the barrier and 198 psi at the bottom.

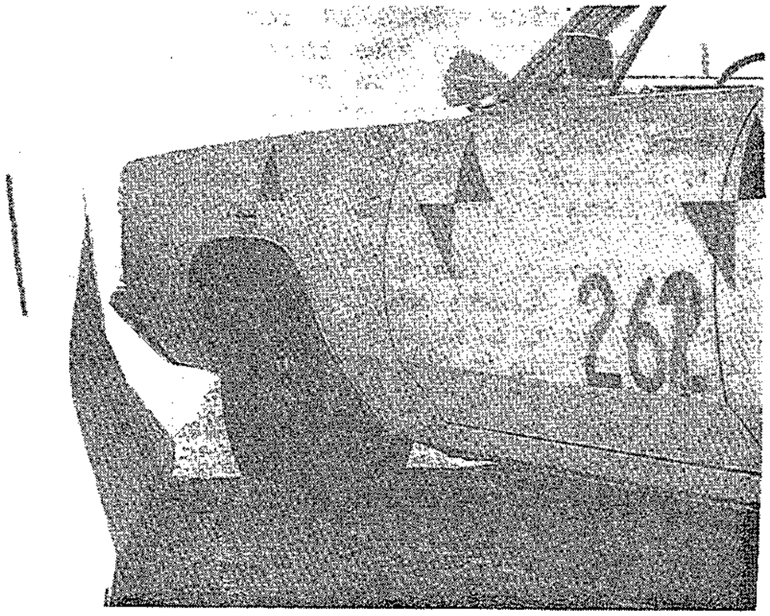


FIGURE 17, CAR LINED UP FOR 25 DEGREE ANGLE IMPACT, TESTS 262-265. BUMPER CONTACTS BARRIER BEFORE TIRE.

The same Mercury sedan that was used in Test 261 hit the barrier at an angle of 25 degrees and a speed of 59 mph. Immediately upon impact the left front quarterpanel and undercarriage were severely crushed. As the car was redirected, the left front fender rose about 3.1 feet with the car tilting about 25 degrees away from the barrier. After less than 13 feet of barrier contact, the car left the barrier nearly airborne and yawing to its right until it landed after traveling about 50 feet in the air. Upon landing the entire weight of the car appeared to be concentrated at the left front portion which had been severely crushed upon barrier impact. This portion of the car appeared to dig into the pavement causing the car to roll over three complete revolutions before stopping in an upright position about 160 feet from the point of barrier impact and about 22 feet from the face of the barrier.

Upon impact, the dummy driver was thrown violently against the left door with its head extending through the open window. The interior of the door was crushed outward, and as the dummy's torso rebounded from it, its head hit the top of the door as it reentered the window. The dummy was then thrown down onto its right side where it remained until the car began rolling over. During the three roll overs, the dummy returned to an upright position and was thrown alternately between the seat and the roof of the car with its head hitting the roof despite the lap belt restraint. The over-all dummy behavior indicates that a live driver would have suffered serious, if not fatal, injuries.

Although the car damage due to impacting the barrier was primarily confined to the left front end, the remainder of the car was totally destroyed by the three roll overs. As shown in Figure 18 the upper framework was severely distorted but the passenger compartment remained intact with the doors locked. Barrier damage was limited to minor scratches in the impact area and tire marks as shown in Figure 19.

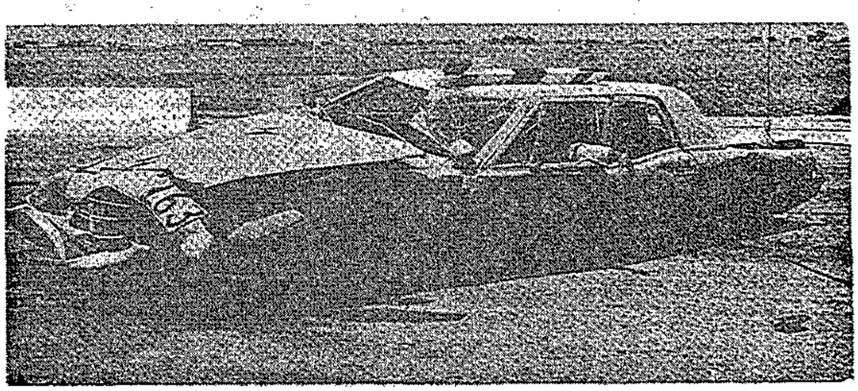


FIGURE 18, TYPICAL DAMAGE RESULTING FROM TESTS 262 AND 263.

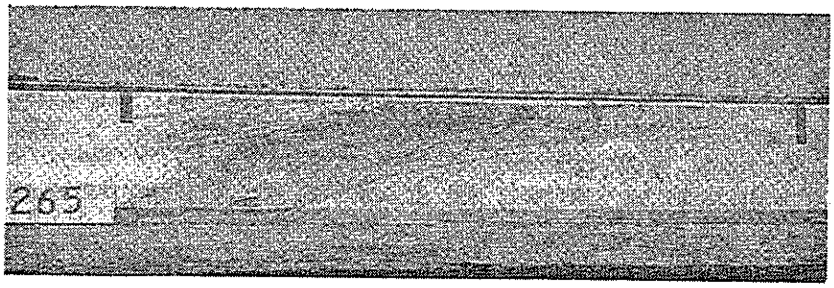


FIGURE 19, TYPICAL TIRE AND BODY MARKS FROM 25 DEGREE IMPACT.

4. Test 263

The test conditions for Test 263 were nominally equivalent to Test 262 except that the point of impact was near the proposed construction joint as shown in Figure 20. The joint consisted of steel plate, bent to match the contours of the barrier, which spanned the 3 foot gap between the two sections of barrier. The steel plate was bolted in place but did not provide any structural continuity through the joint. Test 263 was, therefore, performed to test the adequacy of this joint design.

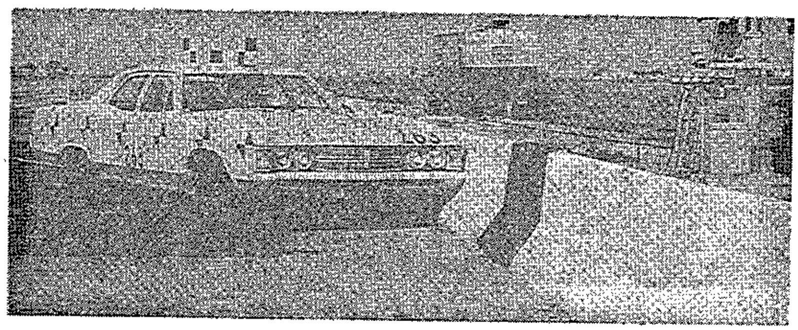


FIGURE 20, IMPACT NEAR JOINT TO PROOF TEST THE JOINT DESIGN.

A Mercury sedan, identical to one used in Tests 261 and 262, traveling at 66 mph and an angle of 25 degrees hit the barrier at a point 23 feet upstream of the joint. The vehicle motion and damage were virtually identical to those of Test 262. Although the dummy's movements were not filmed, inspection of the car's interior following the test indicated that the dummy's response was probably similar to that of Test 262.

Although the barrier successfully retained and redirected the car, it suffered what appeared to be a torsional fracture completely through the concrete section about 9 feet upstream of the impact point as shown in Figure 21. The prestressing strand did not allow the barrier to separate and restricted the movement of the free end to a lateral movement of about 5/16 inch at the top and no lateral movement at the base. Because this movement was small, the barrier was able to perform effectively, but its ability to sustain subsequent severe impacts was significantly reduced. Therefore, the construction plans presented in the Appendix require a reinforced cast-in-place joint in order to provide adequate structural continuity through the joint. The fracture plane was injected with epoxy prior to the next test in an attempt to restore the full continuity of the test barrier.

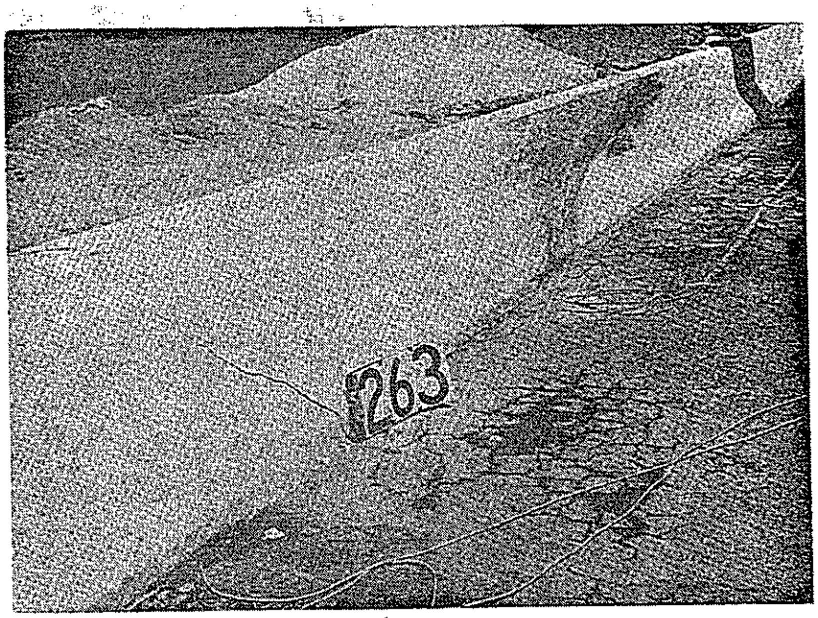


FIGURE 21, TORSIONAL FRACTURE RESULTING FROM IMPACT NEAR JOINT.

5. Test 264

Following the success of the previous tests, it was felt that further construction savings might be realized for this barrier if it could perform effectively with less prestress in the concrete. Therefore, the center strand of the four strands was detensioned prior to Test 264. This lowered the level of prestress in the concrete at the center of the barrier to an estimated 281 psi at the top of the barrier and 148 psi at the bottom. The only other difference between this test and Test 262 was a change in model of vehicle to see if any significant difference in vehicle response could be detected.

A 1969 Dodge sedan traveling at 64 mph hit the center of the barrier at an angle of 25 degrees. The redirection of the car was very similar to the two previous tests except that the car did not roll over. As the car left the barrier, it traveled about 20 feet nearly airborne. Upon landing the weight of the car seemed to be carried by the entire left side of the car as opposed to the previous tests where the car tended to land on its left front. Following the landing, the rear of the car bounced high throwing the weight of the car onto its left front but not enough to make it roll over. As shown in Figure 22, the vehicle suffered severe damage to its left front area, but its exterior was otherwise undamaged except for sheet metal damage along its left side. There was no damage to the barrier.

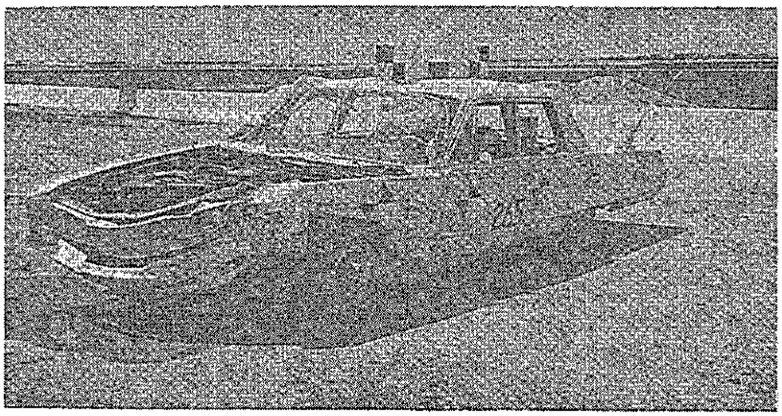


FIGURE 22, TYPICAL DAMAGE RESULTING FROM TESTS 264 AND 265.

Upon impact, the dummy driver was thrown left with its torso crushing the door's interior outward and its head extending through the open window. Concurrent forward motion carried its head downward such that its left cheek and forehead hit the lower frame of the window. Rebounding from this position, the back of the dummy's head hit the top of the window frame as it reentered the window. The dummy was then thrown backward into the seat with its head hitting the head restraint. Subsequent motion was less severe and the dummy remained in an upright position leaning against the door. A live driver probably would have suffered serious injuries in this high speed, sharp angle impact.

6. Test 265

Upon the successful completion of Test 264, it was realized that the prestress in the center of the 150-foot test barrier possibly would not duplicate the prestress that would occur in the center of a 450-foot long section of operational barrier. Realizing that the prestress in the center of a 450-foot barrier could be essentially zero due to subgrade friction and also considering the fracture which occurred in Test 263, a decision was made to conduct Test 265 using the original design consisting of four strands. Therefore, prior to Test 265, the prestress in the concrete at the center of the test barrier was further reduced in order to simulate the prestress in the concrete at the center of a 450-foot section of barrier. This was accomplished by applying a prestress load of 10 kips in each of the four strands which produced prestress in the concrete at the center of the test barrier of about 130 psi at the top and 72 psi at the bottom. All other test conditions were nominally equivalent to Test 264.

A 1968 Dodge sedan traveling at 62 mph hit the center of the barrier at an angle of 24 degrees. The response of the car was almost identical to that of the previous test and the only damage to the barrier was a hairline tension crack running vertically on the face of the barrier opposite the impact point. As shown in Figure 22 damage to the car was similar to, but a little more extensive than, the damage encountered in Test 264. The hood of the car was torn loose upon impact and the rear window shattered as the car landed after redirection. The dummy's response was not filmed during this test, but was probably similar to that of Test 264.

C. Discussion of Test Results

1. Barrier Performance

The overall structural performance of the test barrier was equivalent to the Concrete Barrier Type 50. Except for Test 263, there was no discernible movement of the barrier upon impact, no significant spalling or other damage to the barrier, and no debris dislodged from the barrier. Because the torsional fracture occurred in Test 263, the joint design was changed to the reinforced cast-in-place concrete joint shown in the Appendix. With this design change, the Prestressed Concrete Barrier Type 50 is considered to possess structural properties equivalent to the Concrete Barrier Type 50 and is virtually maintenance free.

2. Vehicle Response

In Test 261, the barrier demonstrated its ability to smoothly redirect a vehicle hitting it at a high speed and low impact angle with virtually no vehicle damage and only minor occupant injury, if any at all. Following the low angle impact, the vehicle exhibited no tendency to rebound into adjacent traffic lanes although no attempt was made to steer it. The overall vehicle response was very similar to Test 161-B[1].

In Tests 262 through 265 the barrier demonstrated its ability to retain a vehicle under very severe impact conditions. Following a violent collision, the vehicle rebounds from the barrier in a disabled condition and travels 150 to 200 feet before coming to a stop in adjacent traffic lanes. Fortunately, these very severe tests represent a very small portion of actual accidents, and are performed as proof tests of the barrier's ability to prevent a grossly errant vehicle from crossing a median into opposing lanes of traffic.

The response of the Dodge sedans in Tests 264 and 265 was almost identical to that of the Dodge sedan in Test 162[1] which was a nominally equivalent test. This indicates that the redirective properties of the Prestressed Concrete Barrier Type 50 are equivalent to those of the Concrete Barrier Type 50. Because the test vehicles are braked by remote control following impact, the post-impact trajectory is not necessarily the same as that of a vehicle being piloted by a live driver.

The response of the Mercury sedans in Tests 262 and 263 was very similar to that of the Dodge sedans except that the Mercury sedans rolled over. This difference in response is attributed to differences in vehicle characteristics, such as weight distribution, suspension system, etc. It must be recognized that the response of the vehicles to these severe impact conditions does not reflect upon their response to normal operating conditions.

3. Deceleration Data

Deceleration data was collected from each test in order to compare the relative severity of various tests and to estimate the extent of injuries an occupant might suffer. The data from the five tests are presented in detail in the Appendix and summarized in Figure 23.

The extent of occupant injuries cannot be determined precisely, but some insight into the degree of severity can be gained by comparing the accelerometer data with criteria developed at Cornell University[5]. This criteria estimates the threshold of severe occupant injuries in terms of passenger compartment decelerations, and is, therefore, dependent upon the degree of occupant restraint as shown in Figure 24. Because the Cornell criteria are established over a 200 msec. time interval, the comparison of 50 msec. values with the threshold values is conservative. Reference 6 explains in detail the reasons for using the 50 msec. time interval. A comparison of the vehicle decelerations of Figure 23 with the criteria of Figure 24 indicates that the occupant of a vehicle hitting the barrier at a high speed and small angle (9.5°) might suffer severe injuries only if lap belts are not used. However, the occupant of a vehicle hitting the barrier at a very high speed and large angle (25°) might suffer serious injuries although fully restrained by a lap belt and shoulder harness.

Further insight into the degree of occupant injury can be obtained by evaluating the data from the three accelerometers in the dummy's head. By integrating the resultant of the head deceleration raised to the 2.5 power over a 50 msec. time interval, the value obtained is called the Gadd Severity Index, and can be compared to injury criteria developed at Wayne State University[7]. A Gadd Severity Index of 1000 represents the threshold of fatal head injuries. The values of this index shown in Figure 23 indicate that occupants of a vehicle striking the barrier at a high speed and severe angle would not suffer fatal head injuries if restrained by a lap belt. Since anthropometic dummies have not been developed that exactly simulate human response during impact, the Gadd Severity Index cannot be considered an exact measure of the extent of head injuries.

FIGURE 23

SUMMARY OF DECELERATION DATA

Test Number	261	262	263	264	265
Impact Angle, degrees	9.5	25	25	25	24
Impact Velocity, mph	61	59	66	64	62
Vehicle C.G. Deceleration (Max. 50 msec. average)					
Lateral, G's	3.9	11.6	-	13.0	-
Longitudinal, G's	0.6	7.0	-	5.2	-
Dummy Chest Deceleration (Max. 50 msec. average)					
Longitudinal, G's	3.2	8.6	-	5.6	-
Dummy Head Deceleration (Max. 50 msec. average)					
Resultant, G's	11.3	26.7	-	30.1	-
Gadd Severity Index (Max. 50 msec. interval)	81	234	-	447	-
Lap Belt Load (Max.), lbs.	-	1350	-	400	-
Impactograph (Units are 1/80 inch)					
Vertical (Max.)	7	9	7	8	13
Longitudinal (Max.)	9	15	-	12	14
Lateral (Max.)	11	17	18	17	18

FIGURE 24

CORNELL VALUES FOR VEHICLE DECELERATION REPRESENTING THRESHOLD OF SEVERE INJURIES

Passenger Restraint	Highest 200 msec. Average Value of Deceleration (G's) Lateral	Longitudinal
Unrestrained Passenger	3	5
Passengers with Lap Belts	5	10
Passengers with Lap Belts and Shoulder Harnesses	10	25

IV. REFERENCES

1. Nordlin, E. F., Field, R. N., and Stoker, J. R., "Dynamic Tests of Concrete Median Barrier, Series XVI," California Division of Highways, August 1967.

2. Lokken, E. C., "Construction of the Concrete Safety Barrier," Portland Cement Association, presented to American Association of State Highway Officials, November 1972.

3. Highway Research Board on Guardrails and Guide Posts, "Proposed Full-Scale Testing Procedures for Guardrails," Circular 482, September 1962.

4. Tutt, P. R., and Nixon, J. F., "Roadside Design Guidelines," HRB Special Report 107, 1970.

5. "Highway Barrier Analysis and Test Program," Summary Report for period July 1960 - July 1961, Cornell Aeronautical Laboratory Report No. VH-1472-V-3, July 1969.

6. Nordlin, E. F., Woodstrom, J. H., and Hackett, R. P., "Dynamic Tests of the California Type 20 Bridge Barrier Rail, Series XXIII," California Division of Highways, October 1970.

7. "10th Stapp Car Crash Conference - Proceedings," November 8-9, 1966, published by Society of Automotive Engineers, Inc., Paper 660793 by Charles W. Gadd, "Use of Weighted-Impulse Criterion for Estimating Injury Hazard," Paper 660803 by Alan M. Nahum, M. D., Arnold W. Siegel, and Stanford B. Trachtenberg, M. D., "Causes of Significant Injuries in Nonfatal Traffic Accidents."

V. APPENDIX

A. Crash Car Equipment

Following is a description of the modifications made to crash cars prior to impact tests. The method of controlling the car remotely is also described.

1. The test vehicle gas tank was disconnected from the fuel supply line, drained and refilled with water. A one gallon safety gas tank was installed in the trunk compartment and connected to the fuel supply line.

2. Three wet-cell storage batteries (6, 8, and 12 volt) were mounted on the floor of the rear seat compartment. They supplied power for the remote control equipment.

3. A solenoid-valve actuated CO_2 system was connected to the brake line for remote braking. With 700 psi in the accumulator tank, the brakes could be locked in less than 100 milliseconds after activation.

4. The ignition system was connected to the brake relay in a failsafe interlock system. When the brake system was activated, the vehicle ignition was switched off. Also, any loss of steering control by reason of a failure of the radio transmitting or receiving systems would automatically energize the brake relay, thus cutting the vehicle ignition and braking the vehicle to a stop.

5. The accelerator pedal was linked to a small electric motor which, when activated, opened the throttle. The motor was activated by a manually thrown switch mounted on the top of the rear fender of the test vehicle.

6. Steering was mechanically accomplished with a 400 inch-ounce stepping motor through a V-belt driven pully attached to the steering shaft. The stepping motor was mounted on a bracket secured to the floorboard of the front seat compartment and activated through the remote radio tuned relay system for right or left turns.

7. A radio control receiver, tone actuated relays, steering pulse and handi-talkie radio were mounted on a chassis bolted to the floorboard of the trunk compartment. Whip antennas for the radio receivers were mounted on the vehicle's rear fenders.

8. A micro switch was mounted below the front bumper and connected to the ignition system. A trip line installed 40 feet from impact triggered the switch; thus opening the ignition circuit and cutting the vehicle motor prior to impact.

9. The left front and left rear tires were painted to delineate wheel climb on the parapet face (front-red, rear-yellow).

B. Photo-Instrumentation

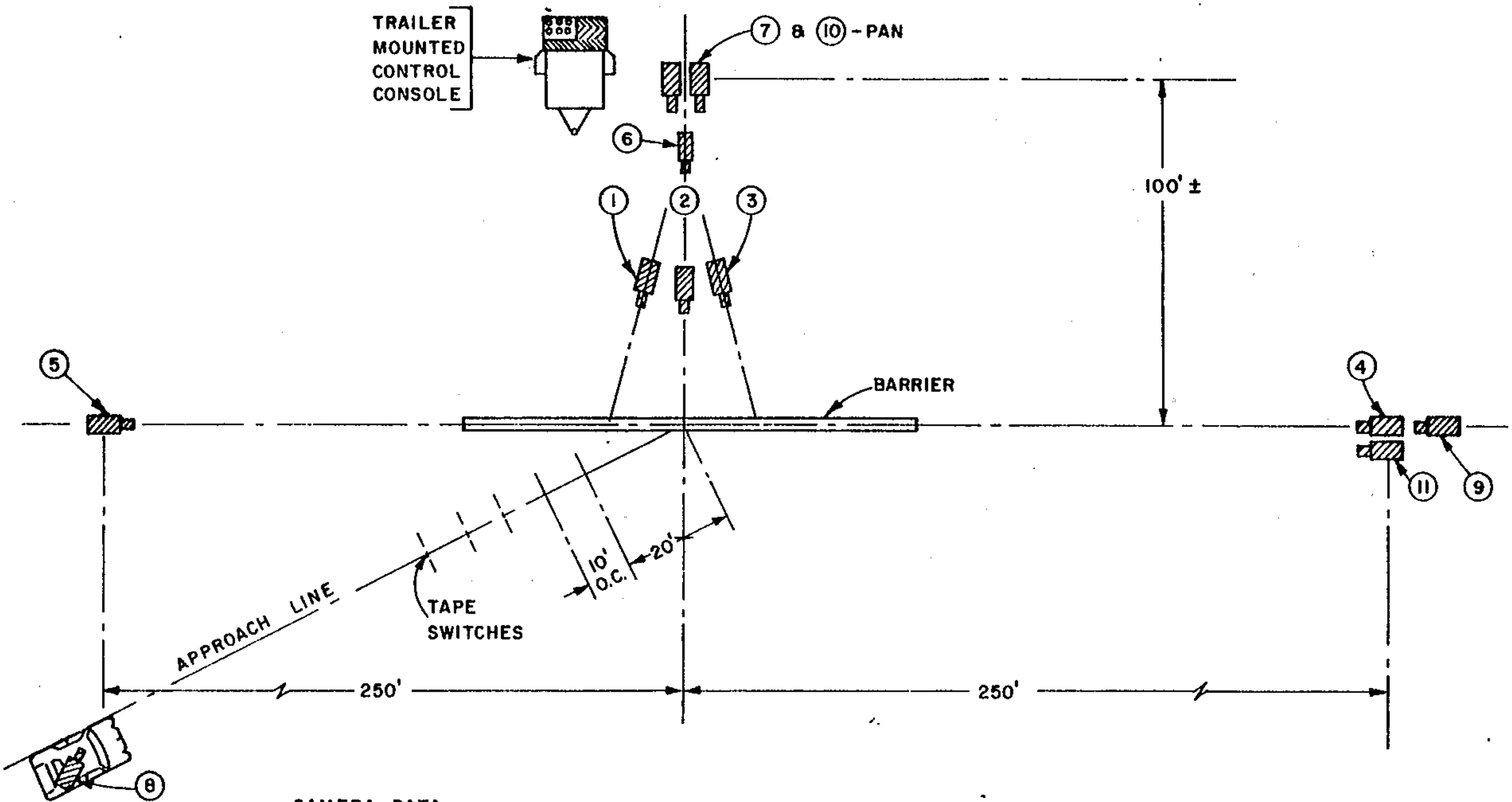
Data film was obtained by high speed cinematography through the use of seven Photosonic 16mm cameras (250-400 frames per second). These cameras were located on tripods to the front, rear, and sides of impact and on a tower 35 ft. above impact. All cameras were electrically actuated from a central control console (Figure 1A). An eighth Photosonic camera was located in the test vehicle to record the motions of the anthropometric dummy. This camera was triggered by a tether-line actuated switch mounted on the rear bumper of the test vehicle.

All cameras were equipped with timing light generators which exposed reddish timing pips on the film at a rate of 1000 per second. The pips were used to determine camera frame rates and to establish time-sequence relationships. Additional coverage of the impacts was obtained by a 70mm Hulcher operating at a rate of 20 frames per second, and a 35mm sequence camera operating at 20 frames per second. Documentary coverage of the tests consisted of normal speed cine-photography and still photographs taken before, during, and after each impact. Data reduction from the high-speed cinematography was accomplished on a Vanguard Motion Analyzer. Procedures taken to instrument the crash vehicle and the test site to assist in the reduction of data are listed below:

1. Targets were attached to the vehicle body and the face of the barrier, and placed at ground locations to the front and rear of the barrier.

2. Flashbulbs, mounted on the test vehicle, were electronically flashed to establish (a) initial vehicle/barrier contact and (b) the application of the vehicle's brakes.

3. Five tape switches were laid on the ground perpendicular to the vehicle path leading into the point of impact. Placed at 10-foot intervals, the switches were actuated sequentially by the tires of the test vehicle, thus triggering a series of flashbulbs. The flashbulbs were in the field of view of all the data cameras and were used to correlate cameras to collision events and to determine the impact velocity.



CAMERA DATA

1 2 3 PHOTO - SONICS, 13.0 MM LENS, 380 FPS,* MOUNTED ON 35' TOWER AND ORIENTED TO COVER THE AREAS INDICATED ABOVE.
4 5 PHOTO - SONICS, 4" LENS, 380 FPS.
6 PHOTO - SONIC, 2" LENS, 380 FPS.
7 PHOTO - SONIC, 2" LENS, 380 FPS.
8 PHOTO - SONIC, 5.3 MM WIDE ANGLE LENS, 200 FPS, INSIDE TEST CAR.
9 HULCHER, 70MM SEQUENCE CAMERA, 12" LENS, MOUNTED ABOUT 12' HIGH ON SCAFFOLD.
10 BOLEX, 1" LENS, 24 FPS.
11 HULCHER, 35 MM SEQUENCE CAMERA.

*FRAMES PER SECOND

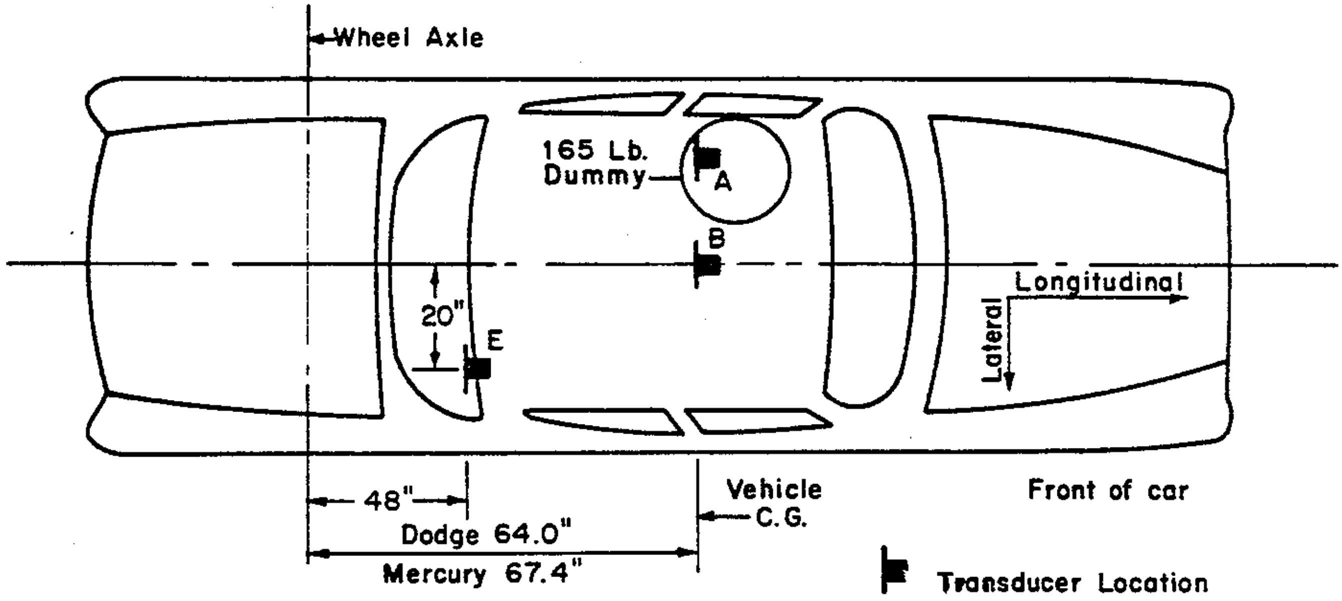
FIGURE 1-A, CAMERA COVERAGE

C. Electronic Instrumentation

A total of six Statham accelerometers, of the unbonded strain gage type, were used for deceleration measurement. Of these, four were mounted in the chest and head cavities of the anthropometric dummy occupant and two were mounted on the floorboard of the test vehicle. In addition one seat belt transducer was installed on the dummy lap belt. Data from these seven transducers were transmitted through a 1000 ft. Belden #8776 umbilical cable that ran from a rear mounting on the test vehicle to a 14 channel Hewlett Packard 3924C magnetic tape recording system. This recording system was mounted in an instrumentation trailer located in the test control area. Figure 2A shows the location of the transducers in the test vehicle. Three pressure activated tape switches were mounted on the pavement at fixed intervals in the vehicle approach path. When activated by the test vehicle's tires, these switches produced sequential impulses which were recorded with the transducer signals on the tape recorder. Concurrently a 100 millisecond time cycle signal was impressed on the tape. All of the tape recorder data were subsequentially played back through a Visicorder which produced an oscillographic trace (line) on paper. Each paper record contained a curve of data from one of the nine transducers, the signals from the three tape switches, and the 100 millisecond time cycle marking. Some of the records of accelerometer data had high frequency spikes which made analysis difficult. Therefore, the original test data was filtered at 100 Hertz with a Krohn-Hite filter. The smoother resultant curves gave a good representation of the overall vehicle deceleration without significantly altering the amplitude and time values of the deceleration pulse. Transducer records from Tests 261, 262, and 264 are presented in Figures 3A through 8A. The electronic instrumentation was not used for Tests 263 and 265.

A mechanical Impactograph was secured to the test vehicle floorboards behind the right front seat. The mechanical stylus of this device records lateral, longitudinal, and vertical impact forces. The record produced is not as accurate as that from the transducers as it is insensitive to the higher frequencies. However, it does provide a comparison of impact severity and serves as a back-up system in case of failure of the electronic system. The traces from the Impactograph are presented in Figures 9A through 11A.

During all five tests, the loads in the prestress strands were monitored by five load cells. Data from these load cells indicated no significant change in load in the strands upon impact. In Test 265, the stresses in the concrete at the center of the barrier were monitored by four strain gages mounted on the concrete. Data from these strain gages indicated no significant change in concrete stresses upon impact.



Accelerometer Location			Orientation
261, 262 & 264	A	Dummy's Head	Longitudinal
"	A	Dummy's Head	Lateral
"	A	Dummy's Head	Vertical
"	A	Dummy's Chest	Longitudinal
"	B	Vehicle Floor	Longitudinal
"	B	Vehicle Floor	Lateral

Seat Belt Transducer

261, 262 & 264 - Location A - Across Dummy's Lap.

Impact-O-Graph

All tests - Location E - Vehicle Floor.

NOTE: Location A (for accelerometers) is on the back of the head or in the chest cavity of the dummy; Location B is on a steel angle bracket welded to the floor at the vehicle center of gravity.

FIGURE 2A - VEHICLE INSTRUMENTATION

Figure 3A, VEHICLE ACCELERATION VS TIME
TEST 261, 61 MPH, 9.5 DEGREES, LAP BELT
DATA FILTERED AT 100 HERTZ

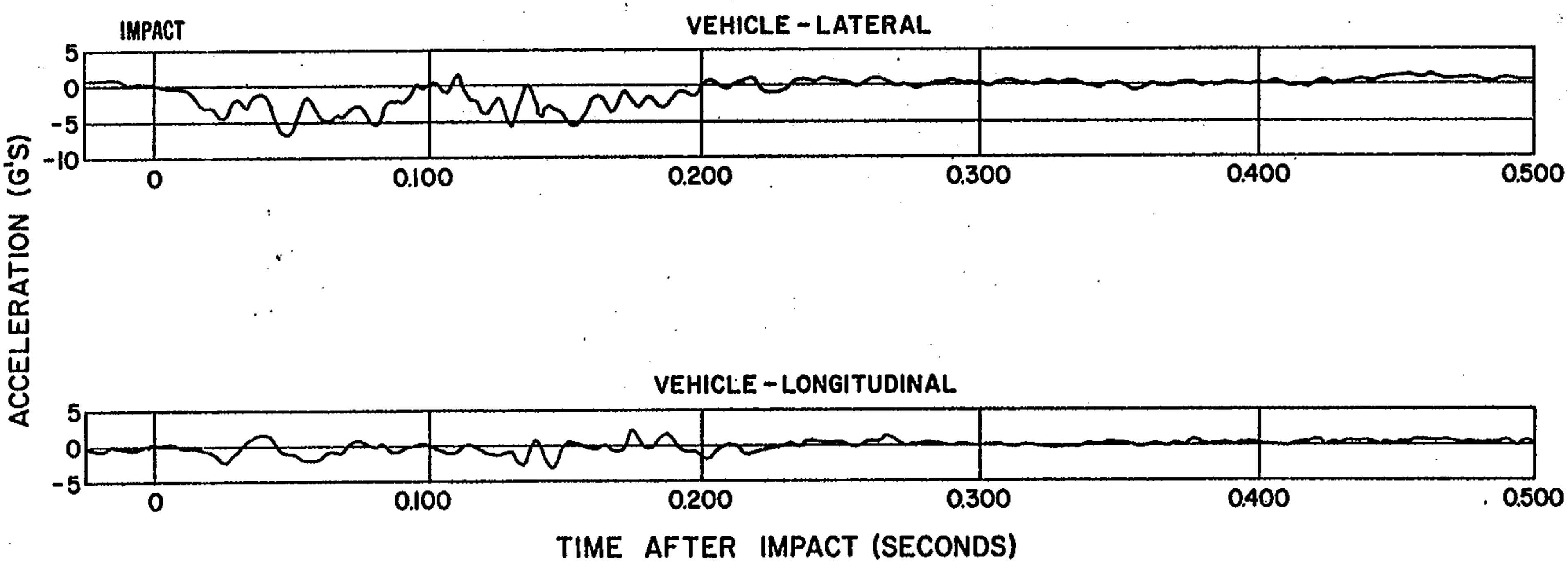


Figure 4A. VEHICLE ACCELERATION VS TIME
TEST 262, 59 MPH, 25 DEGREES, LAP BELT
DATA FILTERED AT 100 HERTZ

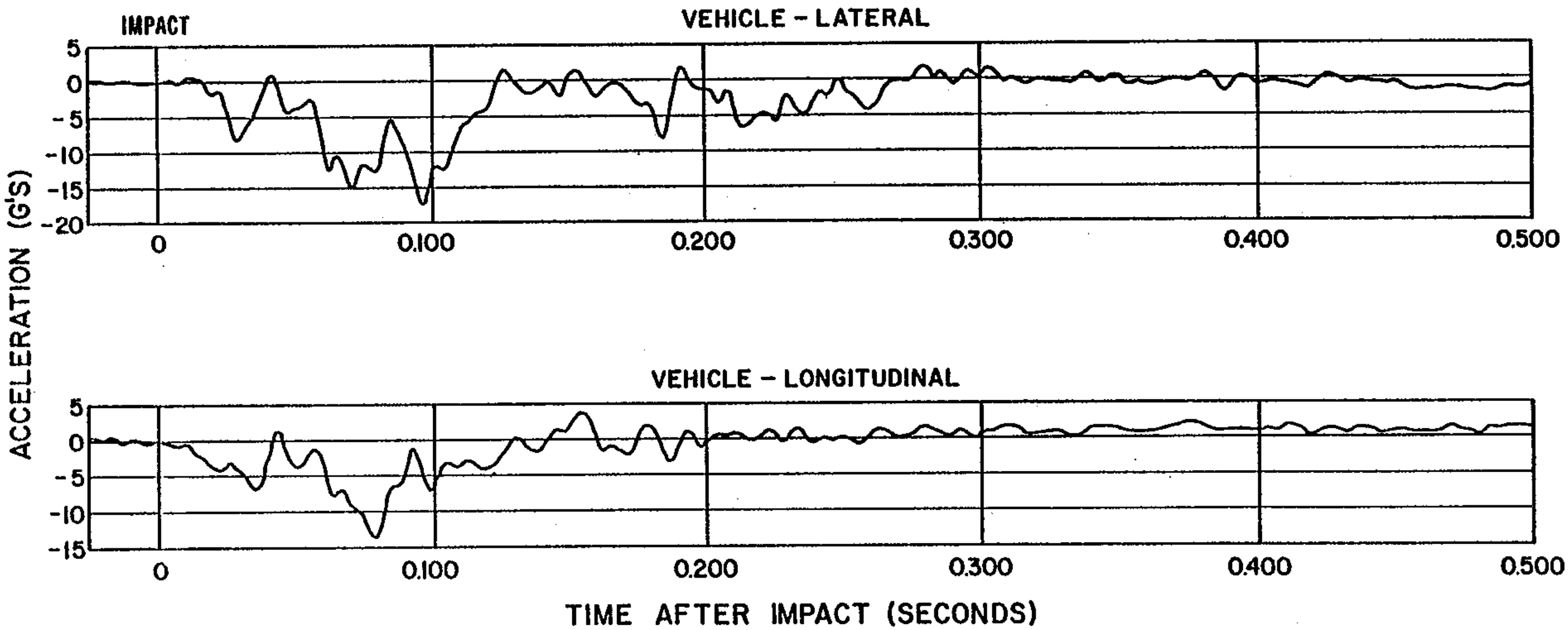


Figure 5A, VEHICLE ACCELERATION VS TIME
TEST 264, 64 MPH, 25 DEGREES, LAP BELT
DATA FILTERED AT 100 HERTZ

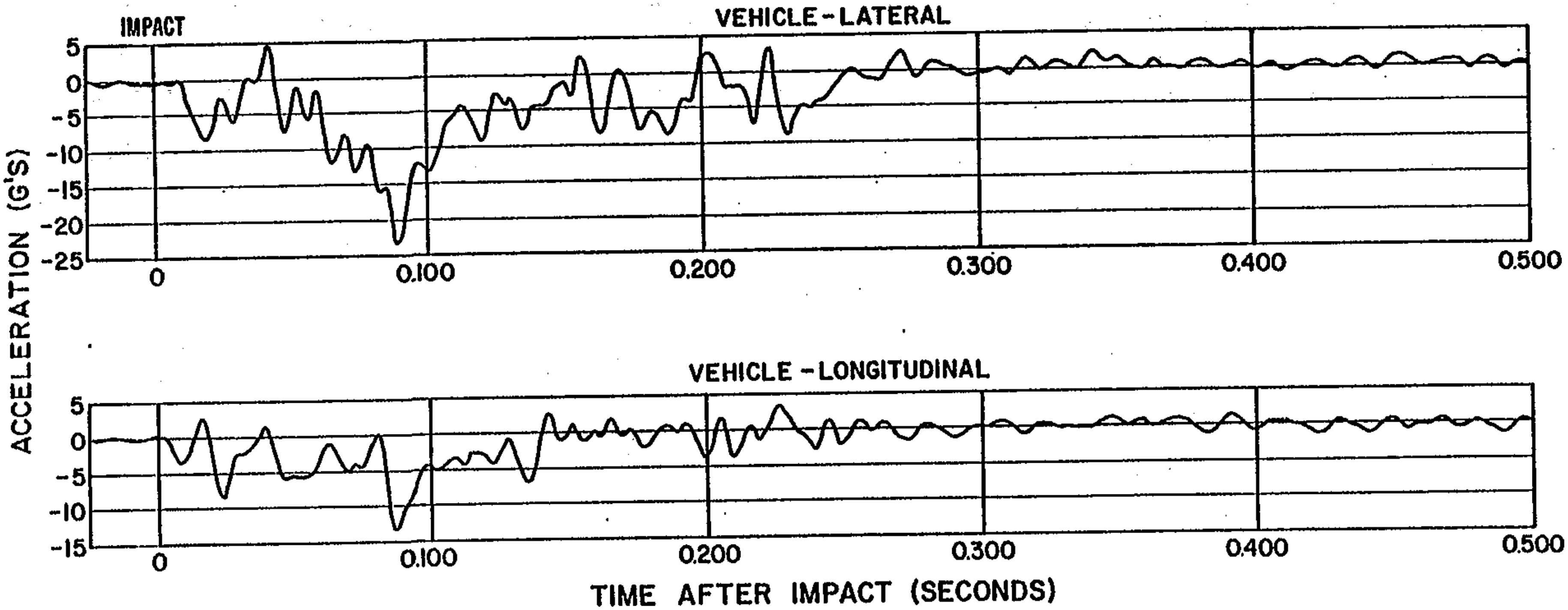


Figure 6A, DUMMY ACCELERATION VS TIME
TEST 261, 61 MPH, 9.5 DEGREES, LAP BELT
DATA FILTERED AT 100 HERTZ

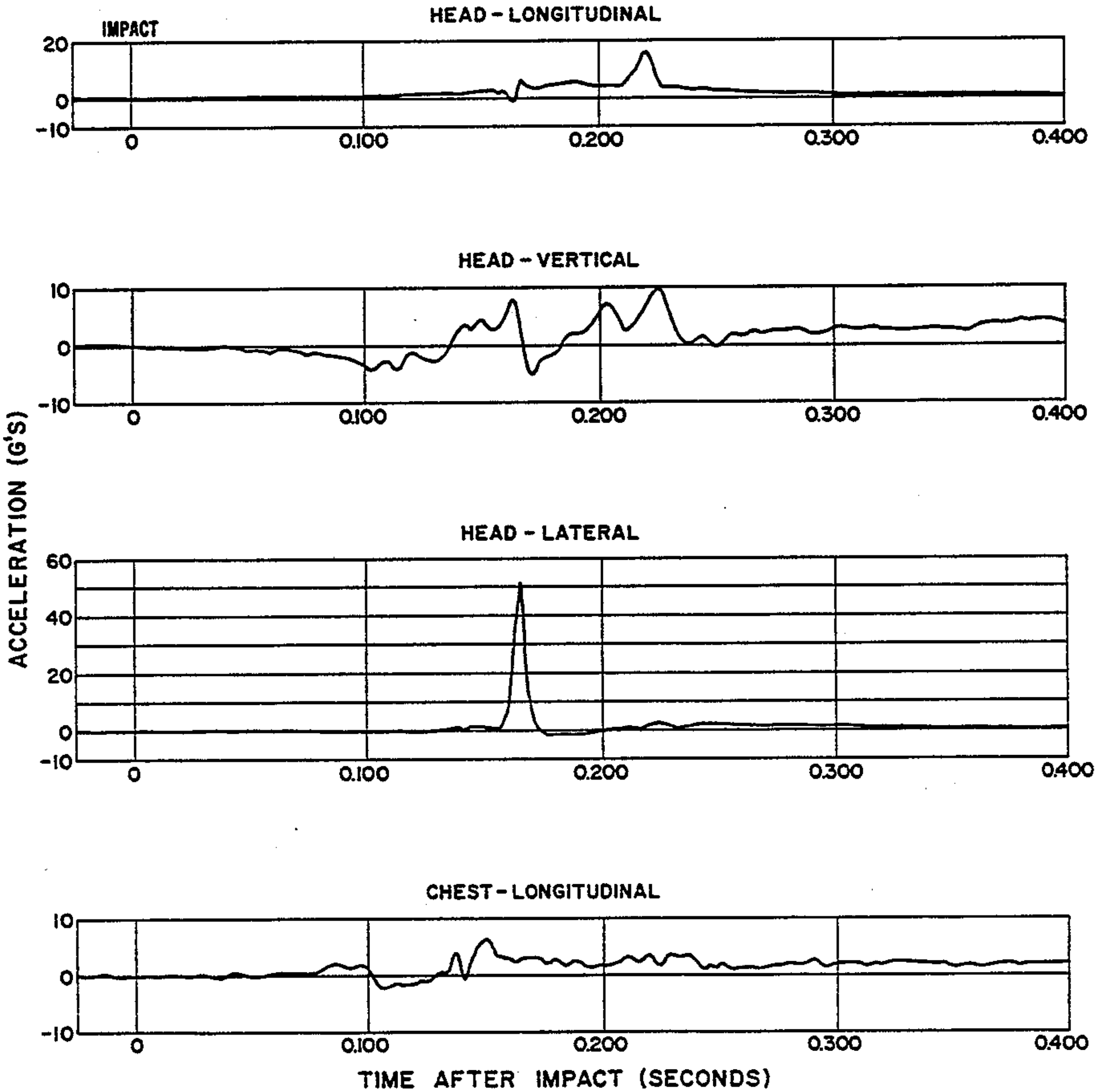


Figure 7A, DUMMY ACCELERATION VS TIME
TEST 262, 59 MPH, 25 DEGREES, LAP BELT
DATA FILTERED AT 100 HERTZ

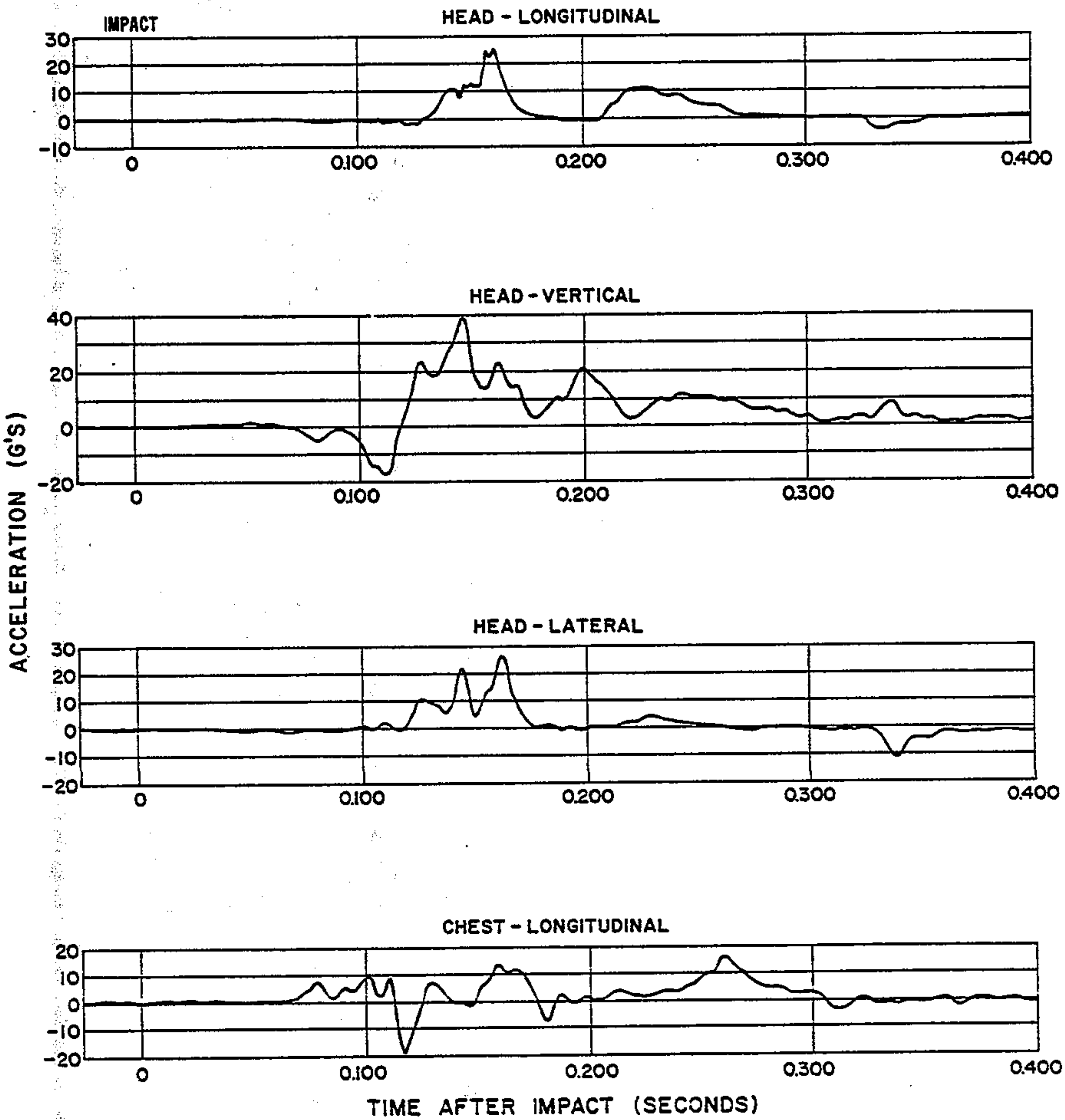
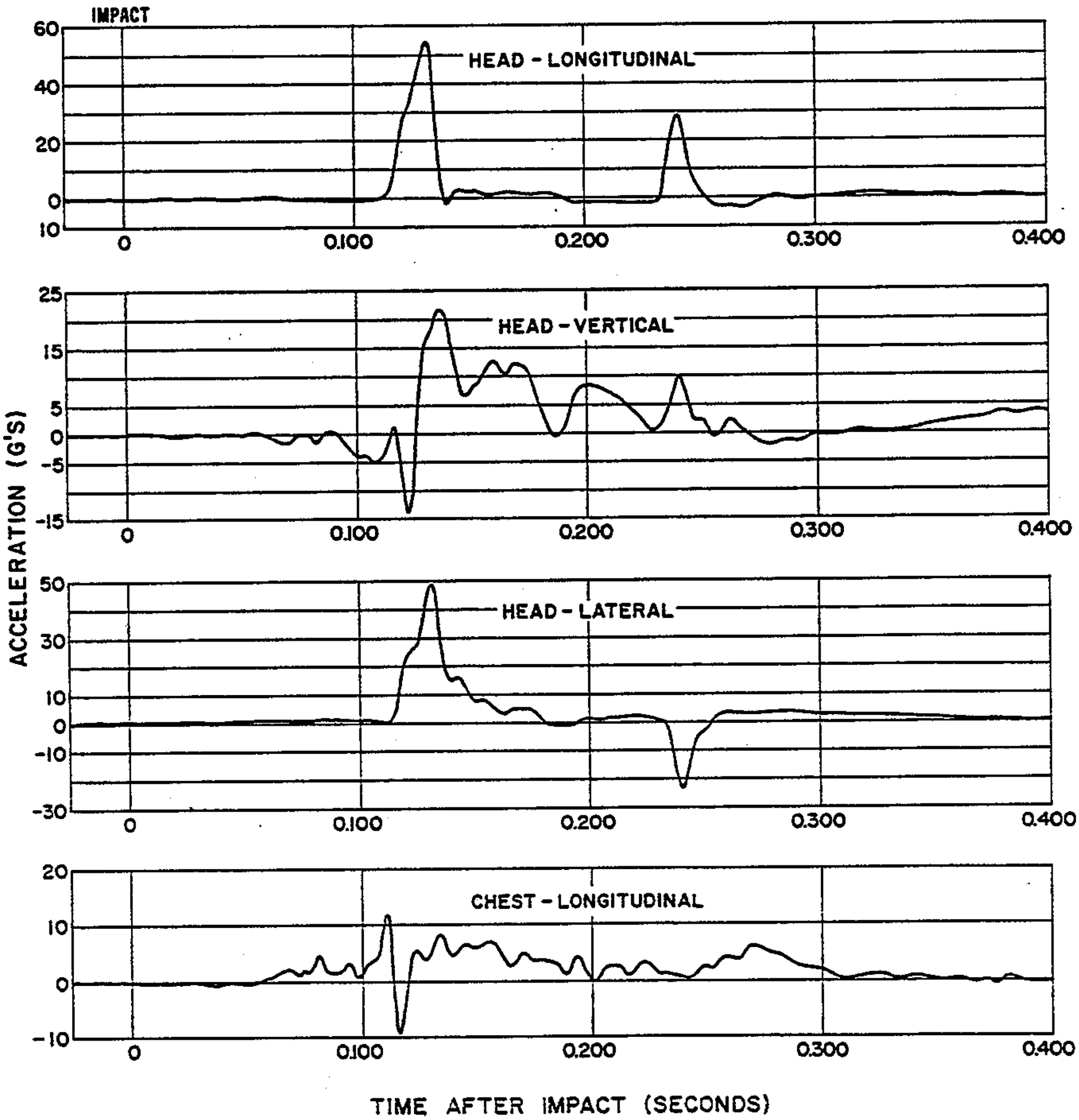
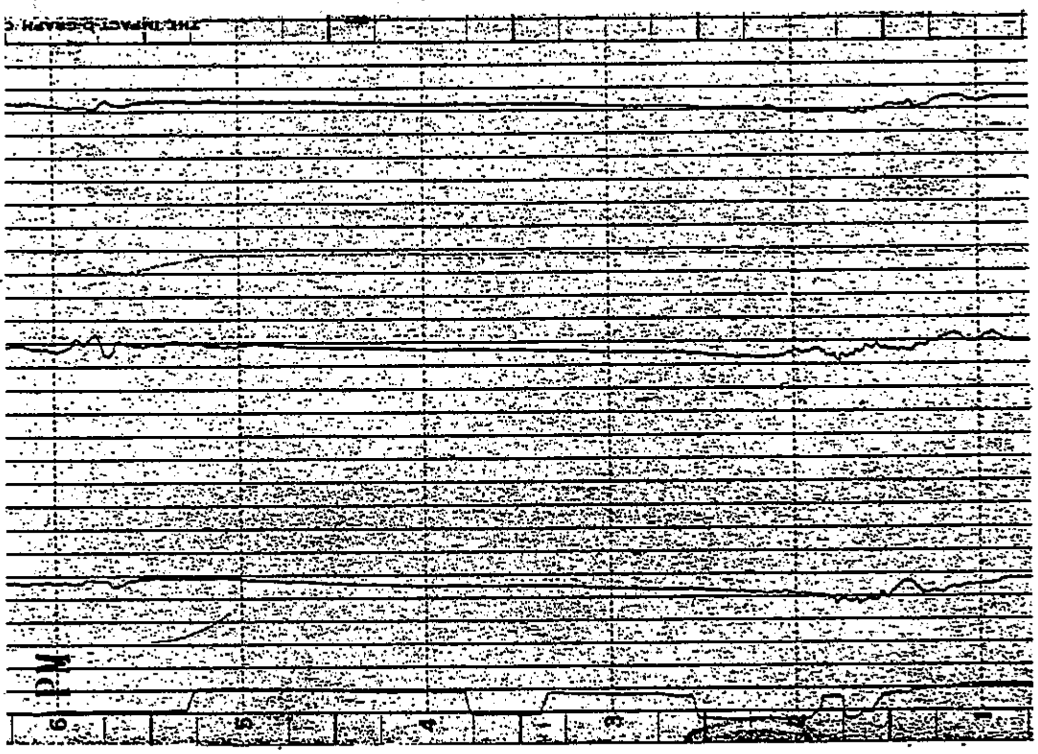


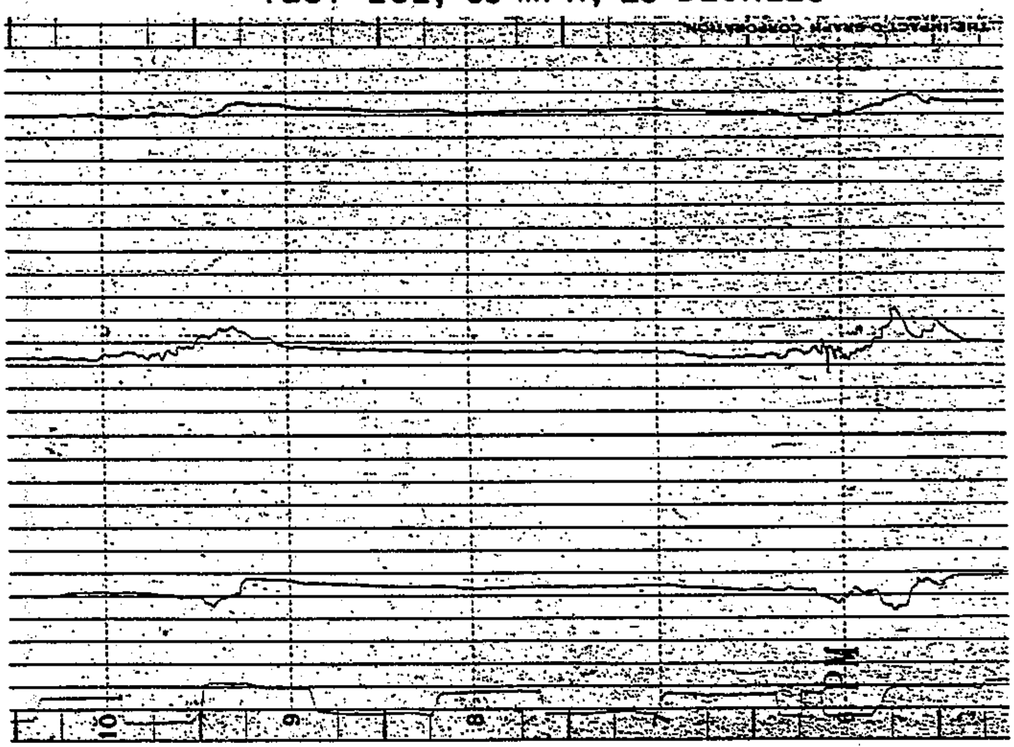
Figure 8A. DUMMY ACCELERATION VS TIME
TEST 264, 64 MPH, 25 DEGREES, LAP BELT
DATA FILTERED AT 100 HERTZ



TEST 261, 61 MPH, 9.5 DEGREES



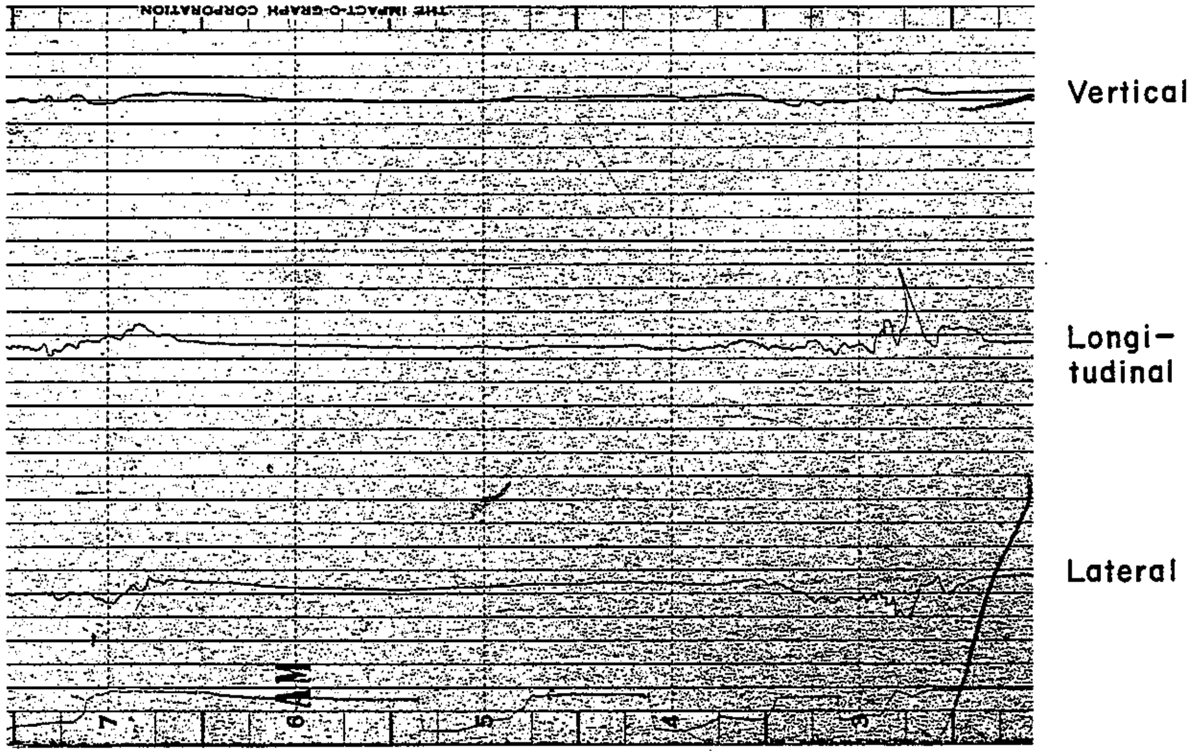
TEST 262, 59 MPH, 25 DEGREES



TIME (6"/SEC±)

FIGURE 9A, VEHICLE IMPACTOGRAPH DATA

TEST 263, 66 MPH, 25 DEGREES



TEST 264, 64 MPH, 25 DEGREES

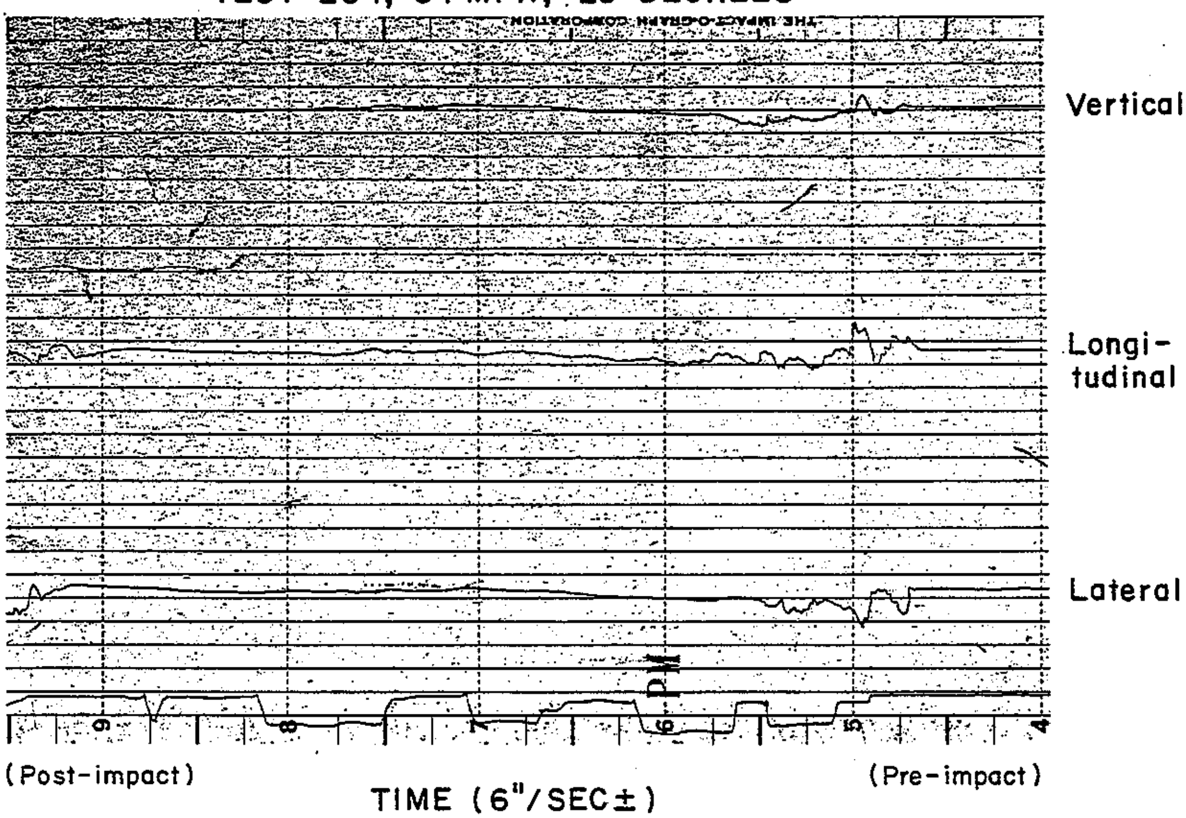


FIGURE 10A, VEHICLE IMPACTOGRAPH DATA

TEST 265, 62 MPH, 24 DEGREES

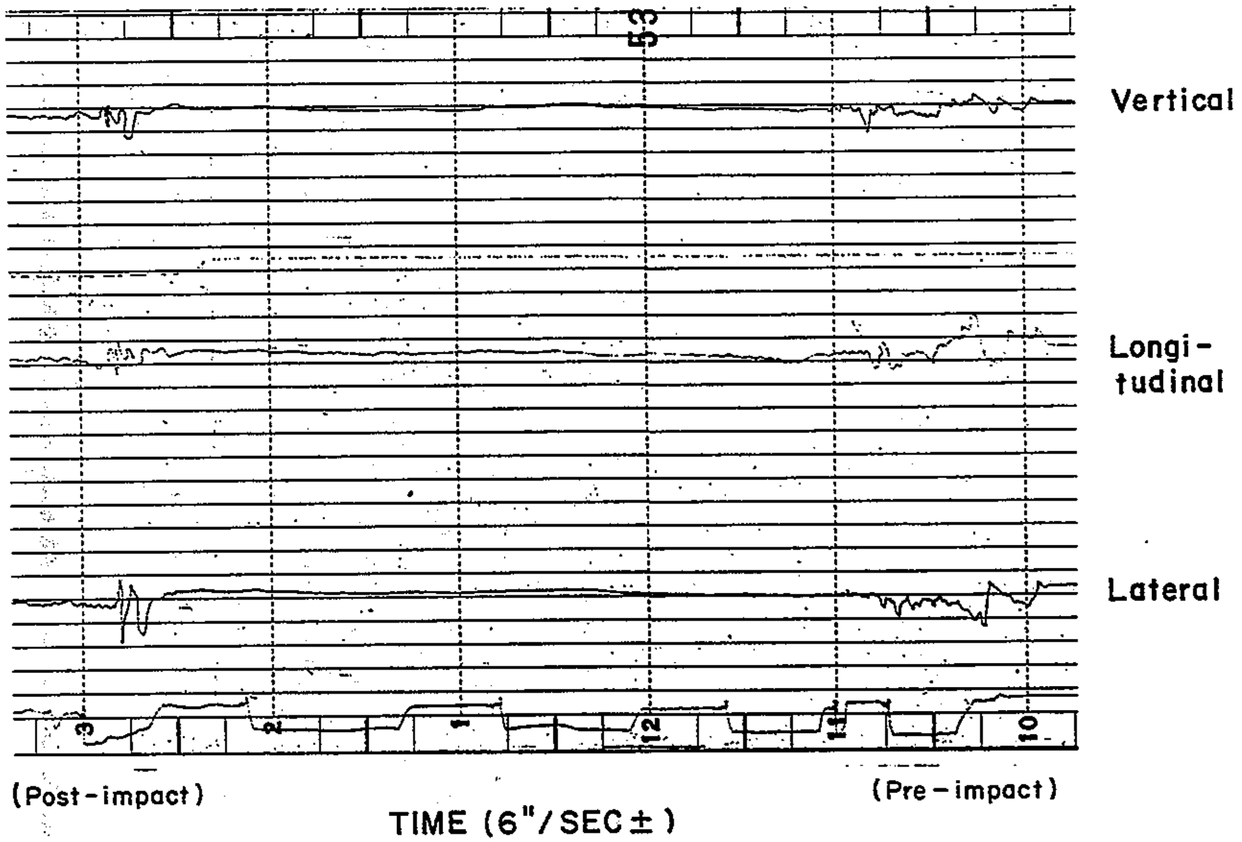


FIGURE 11 A, VEHICLE IMPACTOGRAPH DATA

D. Prestress Losses in Concrete

In order to estimate the loss of effective prestress in the concrete due to friction and/or bond between the test barrier and the asphalt concrete pavement, eight strain gages were mounted on the concrete and monitored while the level of stress in the strands was varied. Because the concrete strain was relatively low (less than 100 microinches/inch) it could not be measured precisely, but the results of this testing are considered a reasonable estimate of the prestress losses. The estimated losses in the 150-foot test barrier were extrapolated to estimate the losses in a 450-foot section of operational barrier (Figure 8), and the prestress conditions for Test 265 attempted to simulate the center of a 450-foot barrier.

The eight strain gages were 6-inch long flat paper Constantan wire gages possessing a gage factor of 2.08 and a resistance of 300 ohms. They were located on both sides of the barrier as shown in Figure 12A to compensate for temperature stresses induced by sunlight shining on one side of the barrier. The loads in the strands were measured by load cells mounted on the individual strands. The results presented in Figures 13A through 16A include stressing of both three (excluding the center strand) and four strands. The location of the center of gravity of the four strands is not significantly different than that of three strands.

The strain levels of these curves were converted to the stress levels of Figure 8 using a concrete Modulus of Elasticity of 4.5×10^6 psi. This value was determined from three standard 6 inch by 12 inch cylinders from the barrier concrete. The cylinders were tested a total of 13 times at an age of 80 days with the stress and strain recorded continuously.

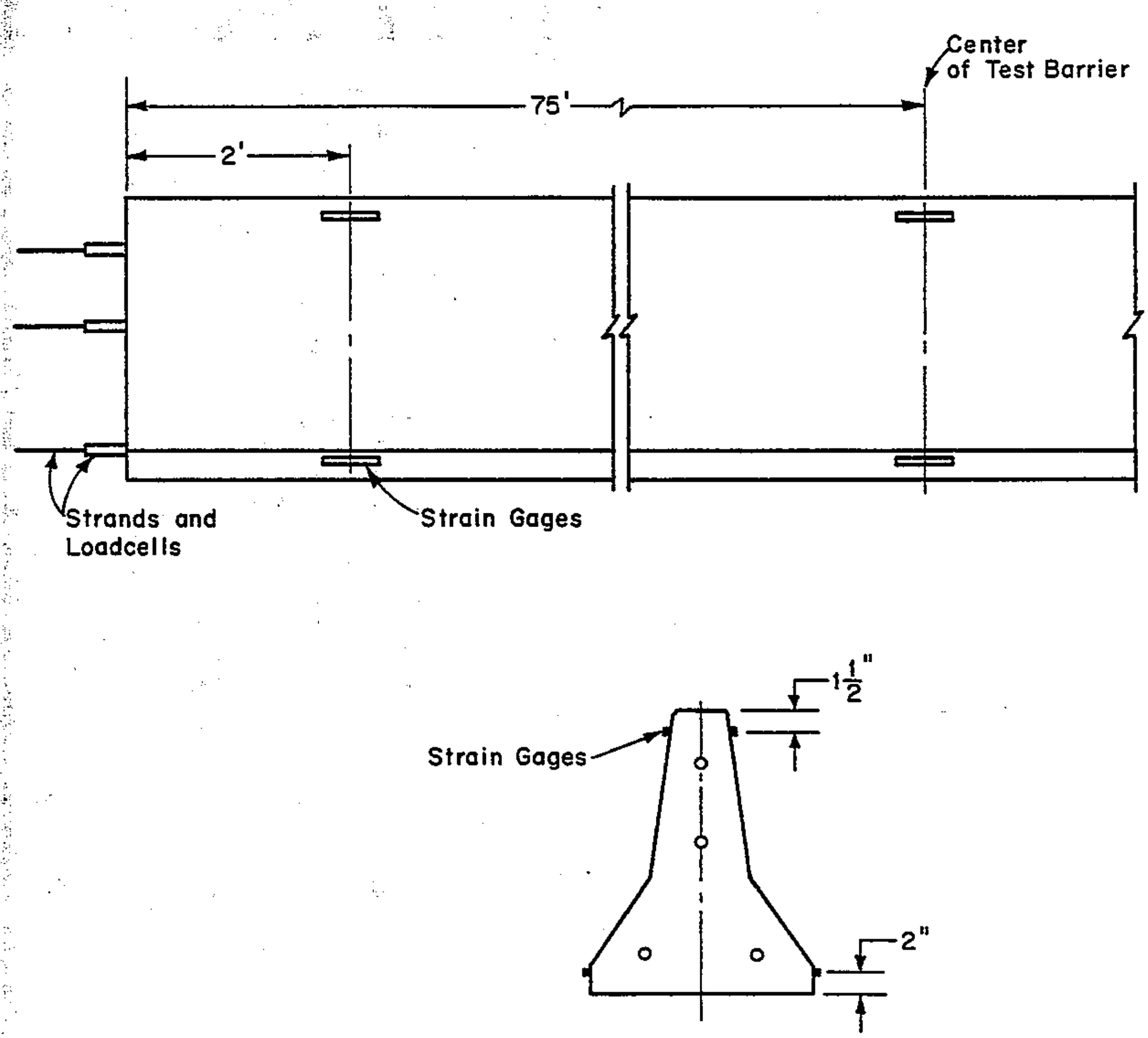
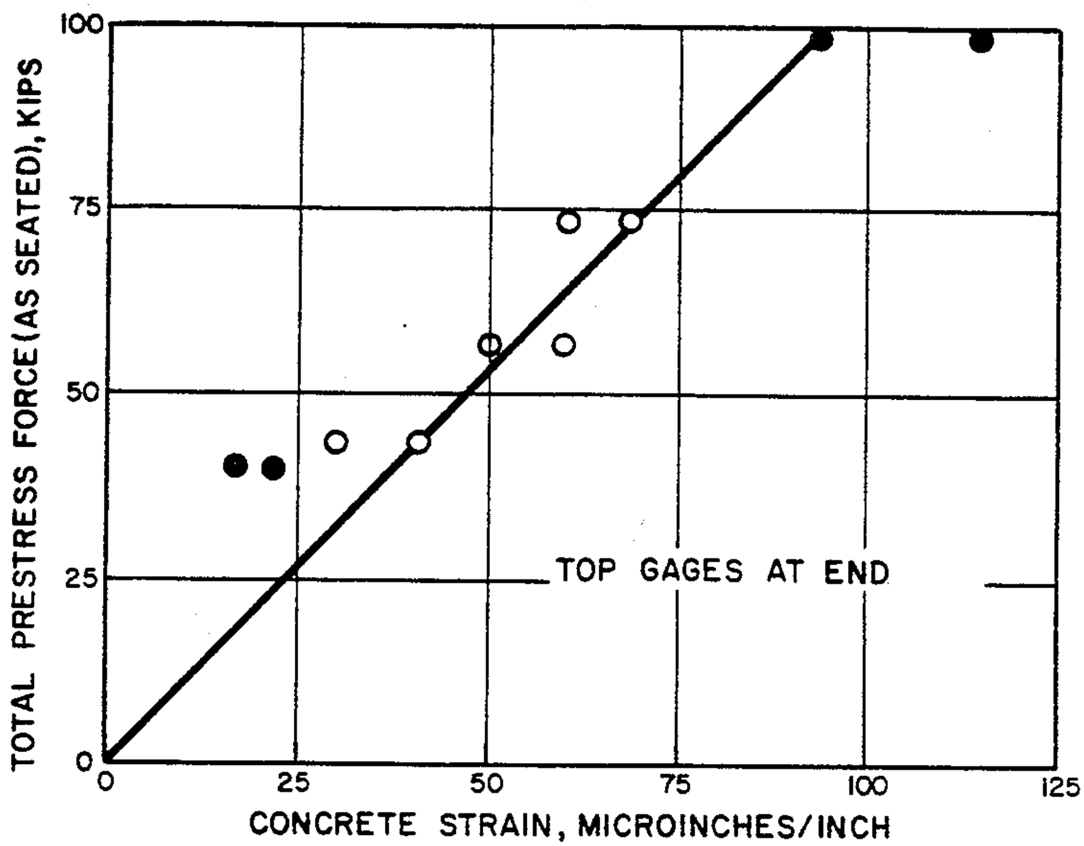


FIGURE 12A, STRAIN GAGE LOCATIONS



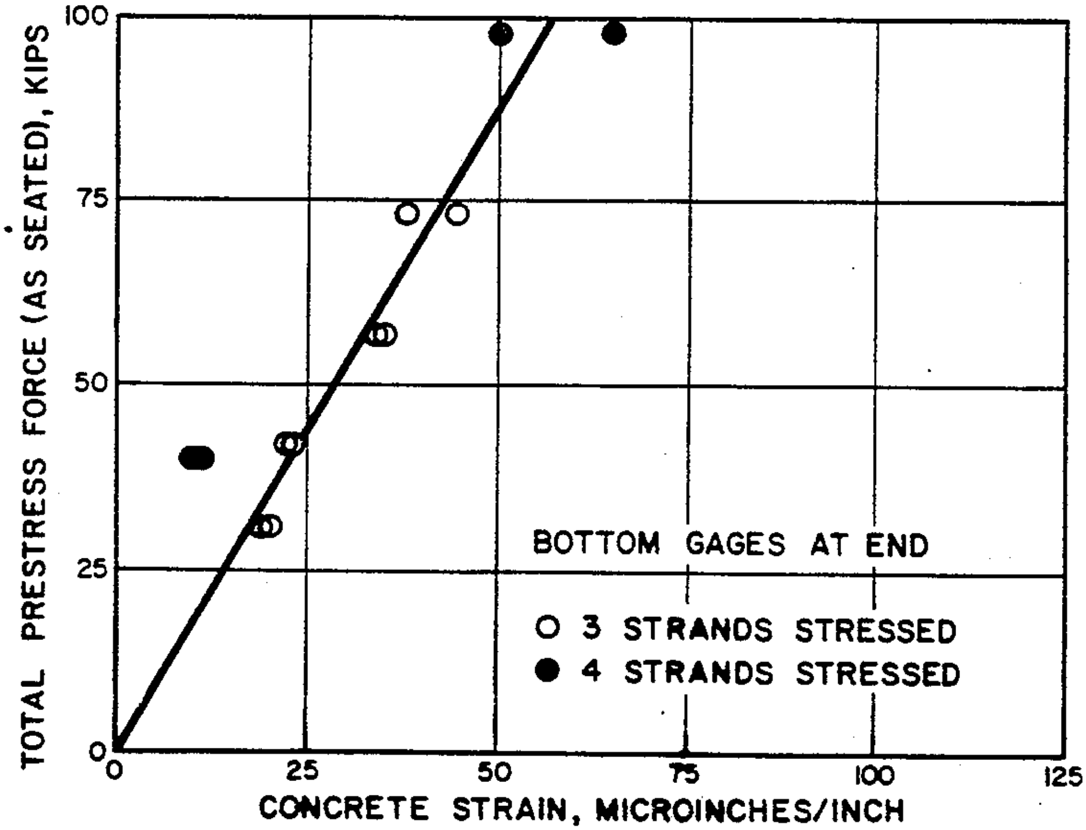
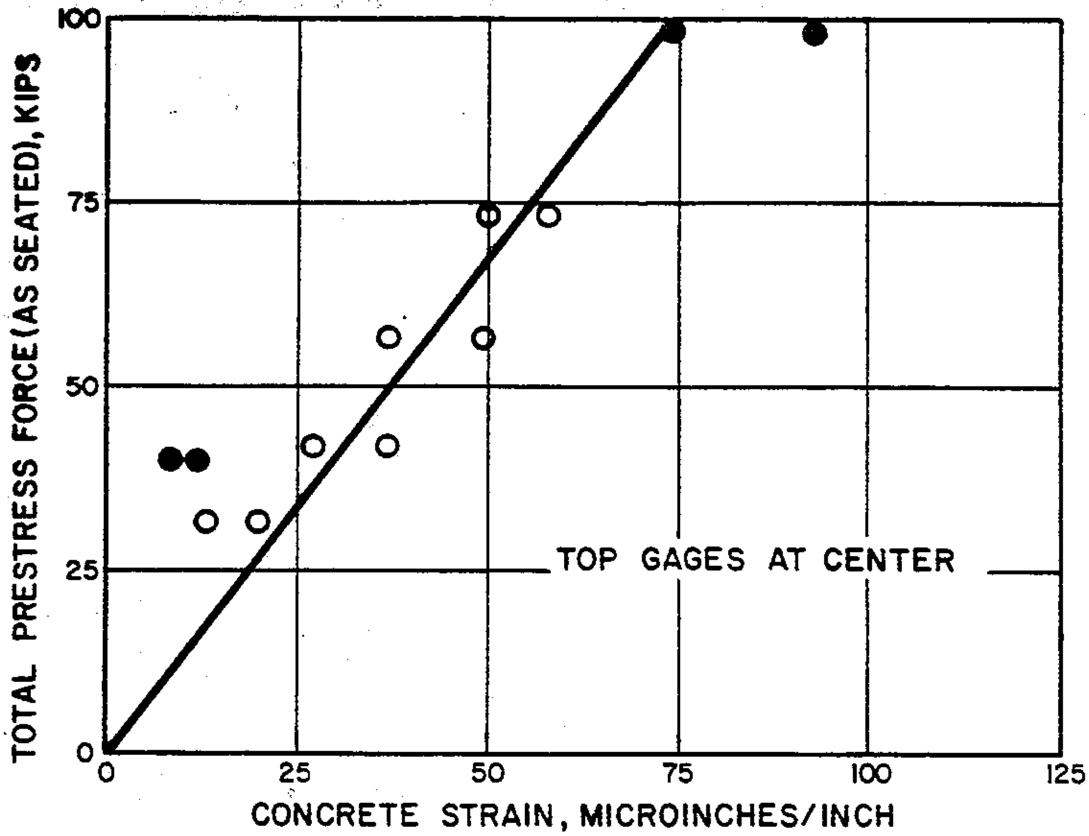


FIGURE 13A, FORCE VERSUS STRAIN AT END



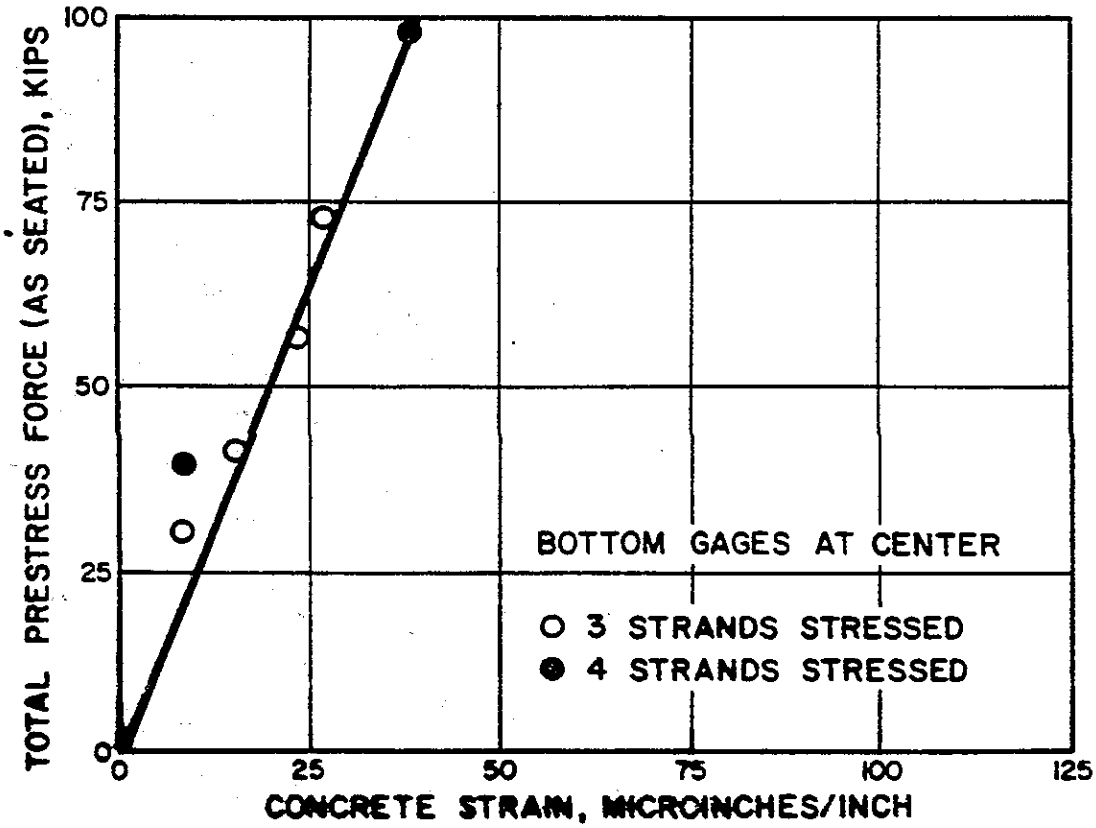


FIGURE 14A, FORCE VERSUS STRAIN AT CENTER

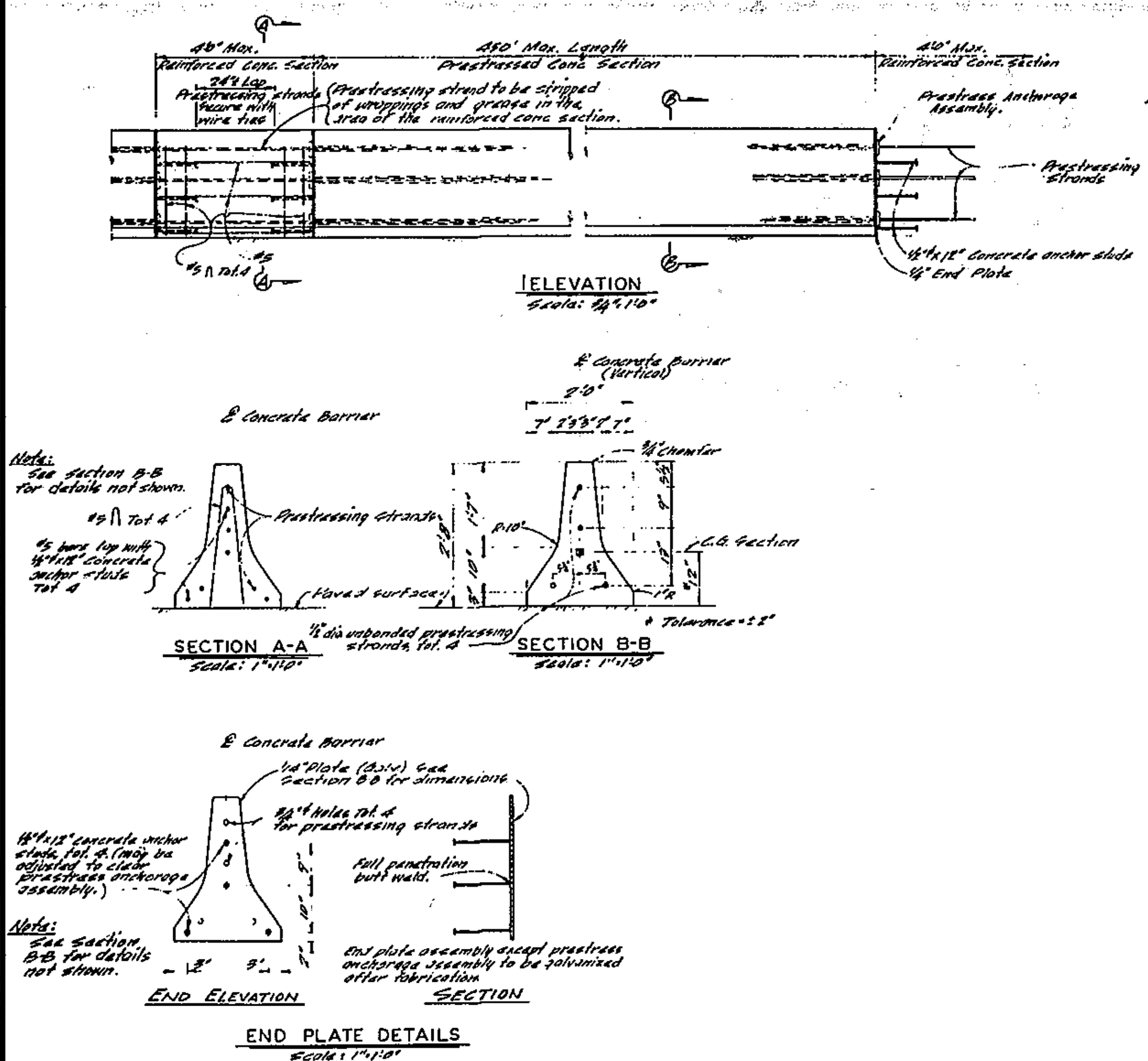
E. Plans and Specifications

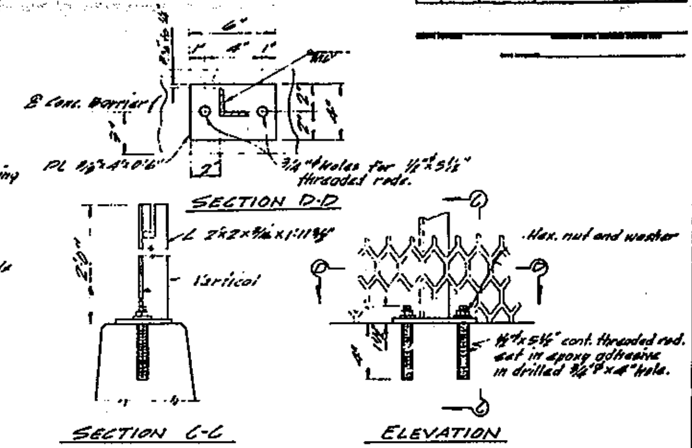
The following plans and specifications for the construction of prestressed Type 50 concrete median barrier are currently approved for use on California highways. The specifications presented are excerpts from the current Standard Special Provisions and are to be used in conjunction with the California Division of Highways Standard Specifications.

Excerpts from Standard Special Provisions (dated 1-2-73)

PRESTRESSED.--Concrete barriers constructed with prestressed concrete sections shall conform to the details shown on the plans and as specified herein.

Prestressing shall conform to the provisions in Section 50, "Prestressing Concrete," of the Standard Specifications except as otherwise specified herein. Prestressing tendons shall not be stressed until the concrete in the barrier section has attained a compressive strength of at least 3000 psi. Prestressing tendons shall be encased in either plastic or metal sheaths which will eliminate bond between the concrete and the prestressing tendon. Voids between the tendon and sheath shall not be grouted. Prestressing strands shall be thoroughly coated with an approved corrosion inhibiting material. End plates for prestressed concrete barrier sections shall be fabricated of mild steel in accordance with the details shown on the plans. End plates shall be hot-dip galvanized in conformance with Section 75-1.05, "galvanizing," of the Standard Specifications. Prestressing strands extending into cast-in-place concrete sections of the barrier shall be cleaned and tied in accordance with details shown on the plans.





GLARE SCREEN POST ANCHORAGE

Scale: 1"=1'-0"

Note:

1. Where glare screen is not placed during initial construction, screen anchor bolts shall be installed.
2. Glare screen posts 12'-0" c-c. For details not shown see Standard Plan A77-B.
3. Install removable expanded mesh panels at approx. 400' intervals

PRESTRESSING NOTES

1. Each 1/2" diameter strand shall be jacked to P_j = 28.5^k and anchored with a seating loss of 1/4" to 3/8". P_j is based on strands having an ultimate strength of 270 ksi.
2. The location of the strands may be varied from that shown with approval of the Engineer.
3. The centroid of the prestressing force shall coincide, within the allowed tolerance, with the center of gravity shown ⊠ of the section.
4. Concrete: $f'c$ = 7400 psi @ 28 days; $f'ci$ = 7000 psi @ time of stressing.
5. Strands may be jacked at one end only.

REDUCED PLAN
USE SCALE BELOW
0 1 2 3
3 INCHES ON ORIGINAL PLAN

INCOMPLETE PLAN FOR DESIGN ONLY
PRINTED
JAN 3 1974
BRIDGE DEPT.
STATE OF CALIFORNIA

BRIDGE DEPARTMENT
DESIGN SECTION 13
R. F. Peters 7/72
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W. Louie 7/72
H. Pohl 7/72

TRANSPORTATION AGENCY

PRESTRESSED CONCRETE BARRIER - TYPE 50

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